Aide-Mémoire

TO

THE MILITARY SCIENCES.

PART P.---R.

CONTAINING

*** THE BINDER *is requested to cancel this page of 'Contents'—the 'List of Plates'—and the 'Notice of this Part,' on the completion of the Work.*

Supply to the Metropolis—Excursion to Windsor, with views and plans; plans of the Stables, &c.—The Two Universities of Cambridge and Oxford, with views and plans of the Colleges; and an Index and Directory. 25 *wood-cuts* . . . . 1*s.*

*** The following gentlemen were contributors to the preceding:

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NEW SERIES OF EDUCATIONAL WORKS;

OR

Volumes intended for Public Instruction and for Reference:

To be published in the course of 1852.

The public favour with which the Rudimentary Works on scientific subjects have been received induces the Publisher to commence a New Series, somewhat different in character, but which, it is hoped, may be found equally serviceable. The Dictionaries of the Modern Languages are arranged for facility of reference, so that the English traveller on the Continent and the Foreigner in England may find in them an easy means of communication, although possessing but a slight acquaintance with the respective languages. They will also be found of essential service for the desk in the merchant's office and the counting-house, and more particularly to a numerous class who are anxious to acquire a knowledge of languages so generally used in mercantile and commercial transactions.

The want of small and concise Greek and Latin Dictionaries has long been felt by the younger students in schools, and by the classical scholar who requires a book that may be carried in the pocket; and it is believed that the present is the first attempt which has been made to offer a complete Lexicon of the Greek Language in so small a compass.

In the volumes on England, Greece and Rome, it is intended to treat of History as a Science, and to present in a connected view an analysis of the large and expensive works of the most highly valued historical writers. The extensive circulation of the preceding Series on the pure and applied Sciences amongst students, practical mechanics, and others, affords conclusive evidence of the desire of our industrious classes to acquire substantial knowledge when placed within their reach; and this has induced the hope that the volumes on History will be found profitable not only in an intellectual point of view, but, which is of still higher importance, in the social improvement of the people; for without a knowledge of the principles of the English constitution, and of those events which have more especially tended to promote our commercial prosperity and political freedom, it is impossible that a correct judgment can be formed by the mass of the people of the measures best calculated to increase the national welfare, or of the character of men best qualified to represent them in Parliament; and this knowledge becomes indispensable in exact proportion as the elective franchise may be extended and the system of government become more under the influence of public opinion.

The scholastic application of these volumes has not been overlooked, and a

NOTICE

TO

THE CONCLUDING PART

OF THE

AIDE-MÉMOIRE TO THE MILITARY SCIENCES.

The Editors of the 'Aide-Mémoire' have to congratulate the Contributors and Subscribers on the completion of the work.

After seven years' labour, under numerous difficulties, the Editors trust it will be found that their labour has not been in vain,—that they have fulfilled the objects proposed in 1845, — and that the 'Aide-Mémoire' will be considered valuable, not only to the Corps of Royal Engineers, but also to the Service in general, in the multifarious avocations common to every branch of the British Army.

G. G. Lewis, Major-General, R.E.
H. D. Jones, Colonel, R.E.
T. A. Larcom, Major, R.E.
J. Williams, Captain, R.E.

December, 1851.

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Aide-Me ICE

TO

THE MILITARY ŚRT OF

ʼRE.

PART R. - - - Z.

CONTAINING

ʼDE-MÉMOIRE TO THE d Contributors, and ssary arrangements urrent year.

*** THE BINDER *is requested to cancel this page of ʻContentsʼ—the ʻList of Platesʼ—and the ʻNotice of this Part,ʼ on the completion of the Work; also to cancel pages* 521–2, vol. ii., *and to substitute the leaf now given.*

LIST OF PLATES.

NOTICE

OF

THE FIFTH PART OF

THE AIDE-MÉMOIRE.

THE First Part of the third and concluding Volume of the 'AIDE-MÉMOIRE TO THE MILITARY SCIENCES' is now submitted to the Subscribers and Contributors, and the EDITORS are enabled to state with confidence that the necessary arrangements have been made for the completion of the work in the course of the current year.

In adverting to the protracted period through which the publication of the volumes of the 'Aide-Mémoire' has already extended, the EDITORS deem it necessary to observe, that this can only be justly ascribed to causes incidental to the nature of the work, the progress of which has in some instances been retarded by an adherence to the alphabetical arrangement originally proposed and adopted.

With a view to render the work as perfect as possible, and to facilitate the means of reference to the respective subjects, it is the intention of the EDITORS to give a copious INDEX in the concluding Part.

It is particularly requested that any corrections or omissions may be noticed as early as possible, that they may be arranged for insertion at the end of the third volume; and it may here be mentioned, with reference to the article 'Quartering of Troops,' contained in the present Part, that the Circular addressed by the Secretary at War to Commanding Officers, and dated the 15th of last month, respecting an increased allowance to married soldiers, for the purpose of enabling them to obtain lodgings out of barracks, will meet the suggestion of Colonel Thomson on that subject.

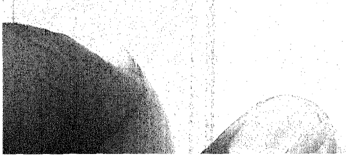
Mr. Heather's correction of the formula for the determination of the seconds pendulum in different latitudes, according to the latest and best experiments, given in page 91, line 4 from the bottom, was not received until that portion of the work had been printed off. It should be

$$l = 39{\cdot}01677 + {\cdot}20027 \sin^2 \lambda.$$

Colonel Dundas's suggestions for the correction of the article 'Ordnance, British,' will be inserted at the end of the work.

G. G. LEWIS, Colonel, R.E.
H. D. JONES, Lieut.-Colonel, R.E.
T. A. LARCOM, Captain, R.E.
J. WILLIAMS, Captain, R.E.

March 1, 1851.



AIDE-MÉMOIRE.

P.

PALÆONTOLOGY*—The doctrine of ancient organic bodies, or the natural history of the earth at successive epochs of its former existence.

In the article 'Geology' it has been shewn that the study of the mineral crust of the earth brings before an observer subjects of the greatest interest in the proofs which it unfolds of the existence of successive races of organic beings, and of the important share which the relics of such organisms had in the formation of that crust.

The great, let it indeed be called the real, theoretic result of such inquiries is this, —that at successive epochs new assemblages of vegetables and animals were called into existence to clothe and people the earth, and that there must have been at each past epoch, as there is in the present, a due relation between the physical condition of the earth's surface and the vital necessities of the beings created to live upon it. The great practical deduction is this,—that, as the continued existence of certain assemblages of organic beings is dependent on the physical conditions of the earth's surface at the time of their existence, the discovery of some of their relics in the strata of the earth indicates the contemporaneous condition of its surface, and thereby affords us a clue to the discovery of other probably existing organisms.

It is thus that the Fossils of the Carboniferous, Triasic, Oolitic, or Cretaceous Periods, when found in any strata, lead us to cherish or to abandon the hope of finding other substances which might be expected to have been associated with them in that particular epoch of the earth's history, and thereby become practical and economic agents of the highest importance.

It was indeed with the ancient as it is with the present state of the earth, that a relation existed between the physical conditions of its surface and the organic structures which were created to flourish upon it; and when it is said that coal may be expected in the Carboniferous strata, nothing more is affirmed than this,—that the conditions of the surface were at that epoch favourable to the accumulation of those vegetable remains which have subsequently, by fossilizing agencies, been converted into coal. We study, in fact, the world in its former stages as we study it now, and from the appearance of some of its parts are enabled to assume the co-existence of others.

The study, then, of Fossils is intimately connected with that of ordinary Natural History; and when the magnitude of its researches, extending as they do to epochs so remote that we cannot measure their antiquity, are considered, the student will no longer be surprised to find that it has become a distinct science under the designation of Palæontology. This study exhibits to us a variety of new and strange

* By Lieut.-Col. Portlock, R. E., F. R. S.

forms, and establishes the great fact, that whole races of animals and vegetables have lived and passed away: nay, it does more than this,—it proves that at successive epochs the assemblages of organic beings have been totally different in their specific characters from those now living, though in no instance created on principles of life different from those developed in existing organisms.

Some of the results which may be derived from this fact are ably set forth in the Tables of Bronn's 'Index Palæontologicus,' made known to English readers by Professor John Nicholl, and which will be now quoted, being preceded by the small explanatory Table of Formations which he has prefixed.

I. Carboniferous Period.	*a.* Lower Silurian. *b.* Upper Silurian. *c.* Devonian. *d.* Mountain Limestone. *e.* Coal Formation. *f.* Lower New Red Sandstone. *g.* Zechstein.
II. Trias Period.	*h.* St. Cassian Beds. *i.* Variegated Sandstone. *k.* Muschelkalk. *l.* Keuper.
III. Oolite Period.	*m.* Lias. *n.* Oolite. *o.* Kimmeridge Clay. *p.* Wealden.
IV. Cretaceous Period.	*q.* Neocomien. *r.* Greensand. *ſ.* Chalk.
V. Tertiary Period.	*s.* Nummulite Formation. *t.* Calcaire grossier. *u.* Middle Tertiary. *v.* Molasse. *w.* Upper Tertiary. *x.* Diluvial.
I.—V.	*y.* All fossil species together. *z.* Living.

The object in referring to the Tables being in this Essay a practical one, many of the speculative reasonings which might be founded upon them will not be brought forward in a detailed manner. It is right, however, to allude to some of them before submitting the Tables for consideration. The duration of species is a subject of great interest, whether viewed as a geological or as a zoological question. It is known to us as a fact dependent on a great Law of Nature, that each individual has an average duration of existence, varying in extent with different species; but it has been

asked whether species also have or have not a definite duration of existence,—whether, in short, a species would continue to exist for an indefinite time, unless cut short by some alteration in the conditions of those natural forces to the influences of which it is exposed. If species have a limited existence, they must necessarily die out, independently of cosmical changes, unless those changes have been so regulated as to correspond with the exact duration of a species, assuming that the lives of all species are uniform in duration. And still more certainly must the disappearance or death of species be partially independent of such changes, when it is assumed that the duration of their lives is variable.

To determine the question of a fixed life or duration of species from the existing creation is almost impossible, as it requires a knowledge of the past as well as of the present, to an extent which has not yet been attained. It is indeed known that some species have disappeared within the range of historic relation, but as most of these have fallen under the destructive agencies of Man, they are not normal, but rather abnormal events. Geology, however, may be expected to aid in solving such a question, as it sets before us the records of the most remote past with a distinctness equal to those of the days only just gone by.

The first belief of the Palæontologist was assuredly that the species of every geological formation were peculiar to it alone, but the most warm advocates of such a theory have gradually so far modified their views as to admit that some few species have occasionally lived beyond the termination of one formation, and passed into another. Bronn has estimated the proportional number which have thus escaped destruction at ·12, and has estimated therefore the average duration of life in species at 1·12 a formation. It is manifest that this can only be received as the expression of a fact, namely, that species have on an average lived 1·12 formation, not as a proof that the *natural* life of a species was limited to that extent of duration. When in this manner species have survived the great cosmical changes which destroyed the great mass of organic beings co-existent with them in a previous formation, have continued to live with undiminished vigour in a second formation, and have at length died away in the heart of that formation, it may fairly be presumed that they have disappeared in conformity with a Law of Nature which limits the duration of each species to some definite period. The scientific interest of this result renders the rigorous examination of all those species which are considered common to more than one formation most desirable; and in deciding on the question the Palæontologist should remember that colour, so important a character in recent objects, is deficient in those he is called upon to examine.

	I. Carboniferous Period.							II. Trias Period.			
	a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*k*	*l*
I. *Plantæ.*	..	..	55	2	879	52	29	..	31	5	62
Cellulares	..	..	6	..	13	1	14	..	..	1	1
Vasculares	..	..	49	2	866	51	15	..	31	4	61
Monocotyledones	..	..	49	2	772	49	13	..	22	1	45
Dicotyledones	..	..	..	..	94	..	2	..	9	3	16
Monochlamydeæ	..	..	..	..	21	..	2	..	9	1	16
Corollifloræ	..	..	..	..	..	..	..	..	..	..	..
Choristopetalæ	..	..	..	..	2	..	..	..	..	..	..
Dubiæ	..	..	..	..	71	2	..	..	..	2	..
II. *Phytozoa.*	36	223	228	263	1	..	17	128	1	19	2
Pseudozoa	..	..	..	..	..	..	..	..	..	..	..
Amorphozoa	1	13	9	..	..	..	..	44	1	2	1
Polygastrica	..	..	..	1	..	..	..	..	..	..	..
Polypi	29	145	137	156	..	..	16	35	..	3	..
Foraminifera	..	..	..	9	..	..	..	..	..	..	..
Bryozoa	12	61	56	64	..	..	13	9	..	1	..
Anthozoa	17	84	81	83	..	..	3	26	..	2	..
Entozoa	..	..	..	..	..	..	..	..	..	..	..
Acalephæ	..	..	..	..	..	..	..	..	..	..	..
Echinodermata	6	65	82	106	1	..	1	49	..	14	1
Stelleridæ	6	65	82	106	1	..	1	9	..	13	1
Echinidæ	..	..	..	..	..	..	..	40	..	1	..
Fistulidæ	..	..	..	..	..	..	..	..	..	..	..
III. *Malacozoa.*	260	416	979	809	143	7	94	603	38	109	26
Tunicata	..	..	..	..	..	..	..	..	..	..	..
Brachiopoda et Rudistæ	151	148	131	199	4	..	35	43	1	10	2
Pelecypoda	25	69	287	186	70	7	44	129	30	71	10
Pteropoda	1	10	13	1	1	..	..	..	..	..	..
Heteropoda	10	24	28	35	7	..	..	..	..	..	..
Protopoda	..	..	4	3	1	..	..	4	..	2	..
Gasteropoda	38	71	246	248	16	..	14	341	6	26	14
(Ctenobranchia	34	68	230	222	15	..	13	335	5	21	9
Cephalopoda	35	94	270	137	44	..	1	86	1	18	..
IV. *Entomozoa.*	218	264	94	43	18	..	4	6	3	12	1
Vermes	4	7	8	10	..	..	1	6	..	4	1
Crustacea	214	257	86	30	10	..	3	..	3	8	..
Cirripedes	..	..	1	..	..	..	..	..	..	..	..
Entomostraca	214	257	85	30	9	..	2	..	1	3	..
Malacostraca	..	..	..	..	..	..	1	..	2	4	..
Myriapoda	..	..	..	..	..	..	..	..	..	..	..
Arachnidæ	..	..	..	..	2	..	..	..	..	..	..
Hexapoda	..	..	..	3	6	..	..	..	..	..	..
V. *Spondylozoa.*	..	7	110	65	80	17	49	4	12	50	77
Pisces	..	7	110	65	78	11	42	4	5	37	[illegible]
Leptocardii, Cyclostomi et Dipnoi	..	..	..	..	..	..	..	..	..	..	..
Elasmobranchii	..	7	38	63	27	..	11	2	1	23	40
Ganoidei	..	..	72	2	51	11	31	2	4	14	18
Teleostei	..	..	..	..	..	..	..	..	..	..	..
Reptilia	..	..	..	..	2	6	7	..	7	13	18
Batrachii	..	..	..	..	..	..	..	..	..	..	..
Ophidii	..	..	..	..	..	..	..	..	..	..	..
Saurii	..	..	..	..	2	6	7	..	7	13	17
Chelonii	..	..	..	..	..	..	..	..	..	..	1
Aves	..	..	..	..	..	?	..	..	..	..	..
Mammalia	..	..	..	..	..	?	..	..	..	..	1
Animalia	514	910	1411	1180	242	24	164	741	54	190	106
Animalia et Vegetabilia	514	910	1466	1182	1121	76	193	741	85	195	168

FOSSIL SPECIES.

III. Oolite Period.				IV. Cretaceous Period.			V. Tertiary Period.						I.—V.	Living.
m	*n*	*o*	*p*	*q*	*r*	*f*	*s*	*t*	*u*	*v*	*w*	*x*	all species together.	*z*
71	152	2	16	..	77	7	10	136	319	110	48	4	2055	69,403
9	46	..	1	..	22	5	9	4	34	19	4	..	188	9100
62	106	2	15	..	45	2	1	132	285	91	44	4	1867	60,303
32	57	..	9	..	14	..	..	132	31	12	3	..	1139	10,629
30	49	2	..	..	31	2	1	108	254	79	41	4	728	49,674
30	42	2	6	..	14	..	..	28	122	38	23	4	358	3246
..	..	..	..	..	..	1	..	..	13	14	1	..	28	23,900
..	1	..	..	..	3	..	..	74	68	27	9	..	175	22,528
..	6	..	..	..	14	1	1	6	51	..	8	..	167	..
29	579	16	2	149	270	1162	35	383	476	502	412	278	4895	4818
..	..	..	..	..	..	6	..	1	..	..	..	..	2	50
..	81	..	..	18	50	108	..	12	6	47	9	30	461	250
..	..	..	..	..	..	19	..	1	..	369	29	223	672	500
3	221	9	..	54	112	673	3	269	390	77	365	21	2528	1810
..	28	..	..	14	10	254	2	97	184	65	220	10	893	1000
..	26	1	..	27	42	323	..	79	129	4	51	3	810	380
3	167	8	..	13	60	96	1	93	77	8	94	8	825	430
..	..	..	..	..	..	..	..	..	..	..	..	..	..	1500
..	..	..	..	..	..	..	19	9	7	..	2	..	43	210
26	276	7	(2)	77	108	289	13	91	73	9	61	4	1189	498
17	92	1	(1)	4	6	36	..	6	3	2	5	..	416	286
9	182	6	(1)	73	102	253	13	84	70	7	56	4	770	146
..	2	..	..	..	..	..	..	1	..	..	..	..	3	66
533	1455	242	102	751	566	1500	39	2125	2725	783	1609	642	13,885	11,482
..	..	..	..	..	..	..	..	1	..	..	..	..	1	71
24	80	3	1	61	26	227	1	13	6	..	23	4	1146	48
212	786	173	77	336	279	697	25	705	783	164	556	189	4836	2413
..	..	..	..	..	..	..	..	2	8	..	2	8	41	62
..	..	..	..	..	1	..	..	..	..	..	..	..	23	85
2	8	..	..	8	8	13	..	32	24	1	34	8	120	64
81	300	53	24	135	125	415	12	1354	1892	218	984	439	6110	8673
79	275	52	23	130	122	395	12	1170	1540	152	853	300	5281	5520)
214	281	13	..	211	127	146	1	18	12	..	4	..	1546	128
50	256	7	69	35	28	114	11	85	251	1381	91	9	2885	67,360
9	58	6	..	19	16	61	6	49	27	1	22	5	292	770
10	152	1	12	16	10	53	5	36	46	14	67	3	894	791
..	4	..	..	4	3	20	..	6	23	1	39	2	87	107
1	16	..	11	7	..	20	..	14	13	2	23	1	563	143
9	132	1	1	5	7	13	5	16	10	11	5	..	244	541
..	2	..	..	..	..	..	..	..	..	14	1	..	17	200
..	1	..	..	..	..	..	..	..	4	132	..	..	131	600
31	43	..	57	..	2	..	..	..	174	1220	1	1	1551	65,000
172	278	42	60	10	70	161	2	367	279	311	110	488	2701	18,085
1[illegible]0	222	27	43	10	68	152	2	266	90	54	54	5	1461	8000
..	..	..	..	..	..	..	..	..	..	..	..	..	..	11
26	49	12	23	5	18	80	..	76	56	24	34	..	550	221
104	172	15	19	5	7	28	2	19	..	5	4	..	572	30
..	1	..	1	..	43	44	..	171	34	25	16	5	339	7738
41	53	15	17	..	5	9	..	33	59	74	8	24	384	1055
..	..	..	..	..	..	..	..	..	35	15	4	12	65	175
..	..	..	..	..	..	..	..	4	3	8	2	2	14	300
40	48	10	12	..	5	9	..	8	8	13	..	4	206	460
1	5	5	5	..	..	..	..	21	13	38	2	6	99	120
..	..	..	..	..	2	..	..	11	25	5	..	101	148	7000
1	3	..	..	..	..	..	..	57	105	178	52	358	708	2030
784	2568	307	233	945	934	2937	87	2960	3721	2977	2222	1417	24,366	101,745
855	2720	309	249	945	1011	2944	97	3096	4040	3087	2270	1421	26,421	171,148

	I. Carboniferous Period.									II. Trias Period.					
	a	*b*	*c*	*d*	*e*	*f*	*g*	Together. *a–g*	True sum. I.	*h*	*i*	*k*	*l*	Together. *h–l*	True sum. II.
I. *Plantæ.*	.	.	21	2	121	15	17	176	124	.	15	4	26	45	39
Cellulares	.	.	2	.	8	1	2	13	8	.	.	1	1	2	2
Vasculares	.	.	19	2	113	14	15	163	116	.	15	3	25	43	37
Monocotyledones	.	.	19	2	101	13	12	147	101	.	10	1	19	30	27
Dicotyledones	.	.	.	.	12	1	3	16	15	.	5	2	6	13	10
Monochlamydeæ	.	.	.	.	10	.	2	12	12	.	5	1	6	12	9
Corollifloræ	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Choristopetalæ	.	.	.	.	.	1	.	1	1	.	.	.	.	.	.
Dubiæ	.	.	.	.	1	.	1	3	2	.	.	1	.	1	1
II. *Phytozoa.*	20	88	68	59	1	1	6	243	146	24	1	12	2	39	34
Pseudozoa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Amorphozoa	1	8	5	.	.	.	.	14	11	6	1	2	1	10	7
Polygastrica	.	.	.	1	.	.	.	1	1	.	.	.	.	.	.
Polypi	13	47	45	39	.	.	6	150	82	14	.	3	.	17	16
Foraminifera	.	.	.	7	.	.	.	7	7	.	.	.	.	.	.
Bryozoa	6	24	22	11	.	.	4	67	38	6	.	1	.	7	7
Anthozoa	7	23	23	21	.	.	2	76	37	8	.	2	.	10	9
Entozoa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Acalephæ	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Echinodermata	6	33	18	19	1	(1)	.	78	52	4	.	7	1	12	11
Stelleridæ	6	33	18	19	1	(1)	.	78	52	3	.	6	1	10	9
Echinidæ	.	.	.	.	.	.	.	.	.	1	.	1	.	2	2
Fistulidæ	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
III. *Malacozoa.*	44	62	94	90	35	4	33	362	149	63	20	44	14	141	77
Tunicata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Brachiopoda	11	13	13	12	5	.	7	61	18	6	1	3	1	11	7
Pelecypoda	5	18	35	33	13	4	18	126	51	24	13	23	7	67	[illegible]
Pteropoda	1	4	3	1	.	.	.	9	5	.	.	.	.	.	.
Heteropoda	1	1	3	3	1	.	.	9	3	1	.	.	.	1	1
Protopoda	1	1	1	1	1	.	.	5	1	1	.	1	.	2	1
Gasteropoda	18	16	30	31	11	.	7	113	54	25	5	13	5	48	32
(Ctenobranchia	17	15	27	28	10	.	6	103	50	24	4	10	4	42	27
Cephalopoda	7	9	9	9	4	.	1	39	17	6	1	4	1	12	6
IV. *Entomozoa.*	37	41	31	21	10	.	2	142	86	1	3	5	1	10	9
Vermes	3	6	4	5	.	.	.	18	14	1	.	2	1	4	3
Crustacea	34	35	27	13	5	.	2	116	64	.	3	3	.	6	6
Cirripedes	.	.	1	.	.	.	.	1	1	.	.	.	.	.	.
Entomostraca	34	35	26	13	5	.	1	114	62	.	1	1	.	2	2
Malacostraca	.	.	.	.	.	.	1	1	1	.	2	2	.	4	4
Myriapoda	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Arachnidæ	.	.	.	.	2	.	.	2	2	.	.	.	.	.	.
Hexapoda	.	.	.	3	3	.	.	6	6	.	.	.	.	.	.
V. *Spondylozoa.*	.	5	47	21	37	4	19	133	103	3	10	19	20	52	[illegible]
Pisces	.	5	47	21	35	1	15	124	94	3	3	12	10	28	[illegible]
Leptocardii, Cyclostomi et Dipnoi	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Elasmobranchii	.	5	20	19	17	.	7	68	52	1	1	5	5	12	7
Ganoidei	.	.	27	2	18	1	8	56	42	2	2	7	5	16	11
Teleostei	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Reptilia	.	.	.	.	2	3	4	9	9	.	7	7	9	23	18
Batrachii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ophidii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Saurii	.	.	.	.	2	3	4	9	9	.	7	7	9	23	18
Chelonii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Aves	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Mammalia	.	.	.	.	.	.	.	.	.	.	.	.	1	1	1
Animalia	101	196	240	191	83	9	60	880	484	91	34	80	37	242	[illegible]
Animalia et Vegetabilia	101	196	261	193	204	24	77	1056	608	91	49	84	63	287	[illegible]

SSIL GENERA.

III. Oolite Period.						IV. Cretaceous Period.					V. Tertiary Period.								I.—V.		
m	n	o	p	Together. m–p	True sum. III.	q	r	f	Together. q–f	True sum. IV.	s	t	u	v	w	x	Together. s–x	True sum. V.	Formations. a–x	Periods. I.–V.	True sum.
30	54	1	12	97	75	.	32	5	37	36	8	30	115	53	31	.	237	189	592	463	350
5	15	.	2	22	18	.	9	4	13	12	4	2	16	6	4	.	32	21	82	61	38
25	39	1	10	75	57	.	23	1	24	24	4	28	99	47	27	.	205	168	510	402	312
18	25	.	5	48	39	.	9	.	9	9	3	9	16	6	2	.	36	27	270	203	152
7	14	1	5	27	18	.	14	1	15	15	1	19	83	41	25	.	169	141	240	199	160
7	11	1	5	24	15	.	9	.	9	9	.	7	36	17	16	.	76	57	133	102	70
.	.	.	.	.	.	.	.	1	1	1	.	.	8	7	.	.	15	13	16	14	14
.	1	.	.	1	1	.	3	.	3	3	.	11	31	14	6	.	62	57	67	62	59
.	2	.	.	2	2	.	2	.	2	2	1	1	8	3	3	.	16	14	24	21	17
14	122	8	.	144	125	63	83	184	310	199	13	115	134	115	117	53	547	307	1283	811	524
.	.	.	.	.	.	.	.	1	1	1	.	1	.	.	.	.	1	1	2	2	2
.	10	.	.	10	10	6	12	23	41	26	.	9	5	10	3	4	31	17	106	71	42
.	.	.	.	.	.	.	.	7	7	7	.	.	2	63	14	32	111	80	119	88	84
4	68	5	.	77	70	28	42	100	170	105	3	79	110	37	81	16	326	164	740	437	251
.	14	1	.	15	14	8	8	41	57	38	2	24	45	29	43	8	151	76	230	126	81
.	24	1	.	25	24	13	16	37	66	44	.	28	37	4	16	3	88	56	253	165	97
4	30	3	.	37	32	7	18	22	47	27	1	27	28	4	22	5	87	41	257	146	73
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	1	1	1	3	1	.	.	1	.	5	3	6	4	3
10	44	3	.	57	45	29	29	52	90	59	7	25	17	5	18	1	73	42	310	209	142
7	19	1	.	27	21	3	2	12	17	15	.	3	2	1	5	.	11	6	143	103	77
3	23	2	.	28	22	26	27	40	73	44	7	21	15	4	13	1	61	35	164	103	62
.	2	.	.	2	2	.	.	.	.	.	.	1	.	.	.	.	1	1	3	3	3
78	132	66	27	303	157	116	101	146	363	181	25	199	218	93	209	146	890	301	2059	865	473
.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	1	1	1	1	1
3	5	2	.	10	6	8	3	13	24	16	1	3	2	.	3	1	10	5	116	52	29
45	74	43	13	175	85	61	53	68	182	83	13	77	85	41	85	54	355	113	905	362	174
.	.	.	.	.	.	.	.	.	.	.	.	1	5	.	6	.	12	6	21	11	10
.	.	.	.	.	.	.	1	.	1	1	.	.	.	.	.	.	.	.	11	5	4
1	2	.	.	3	2	2	2	3	7	3	.	3	4	1	3	3	14	4	31	11	5
18	38	16	14	86	48	31	31	52	114	62	9	111	116	51	111	88	486	166	801	362	202
17	33	15	11	76	41	28	29	44	101	54	9	88	89	35	84	62	367	123	689	295	175)
11	13	5	.	29	16	14	11	10	35	16	2	3	6	.	1	.	12	6	127	61	48
32	88	2	41	173	140	10	8	24	42	32	3	21	134	431	19	6	614	516	981	783	686
2	7	1	.	10	7	3	3	8	14	8	2	4	5	1	5	3	20	6	66	38	21
5	45	1	3	54	48	7	5	16	28	24	1	17	17	15	13	2	65	42	269	184	165
.	1	.	.	1	1	1	1	4	6	4	.	2	8	1	6	1	18	10	26	16	13
1	4	.	2	7	5	1	.	1	2	2	.	2	1	1	1	1	6	2	131	73	70
4	40	1	1	46	42	5	4	11	20	18	1	13	8	13	6	.	41	30	112	95	82
.	2	.	.	2	2	.	.	.	.	.	.	.	.	6	.	.	6	6	8	8	7
.	1	.	.	1	1	.	.	.	.	.	.	.	4	50	.	.	54	53	57	56	55
25	33	.	38	106	82	.	.	.	.	.	.	.	108	359	1	1	469	409	581	497	438
1	83	22	23	169	119	4	44	63	111	83	.	178	117	151	29	152	627	459	1092	801	731
3	52	11	9	105	71	3	37	53	93	69	.	126	35	31	17	1	210	160	560	412	355
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
12	17	5	4	38	25	1	16	24	41	26	.	20	15	12	10	.	57	32	216	142	110
21	34	6	4	65	44	2	4	8	14	8	.	10	3	2	1	.	16	12	167	117	96
.	1	.	1	2	2	.	17	21	38	35	.	96	17	17	6	1	137	116	177	153	149
7	29	11	14	61	45	1	7	8	16	12	.	12	20	22	4	10	68	43	177	127	116
.	.	.	.	.	.	.	.	.	.	.	.	.	7	9	1	3	20	14	20	14	14
.	.	.	.	.	.	.	.	.	.	.	.	3	1	4	.	1	9	7	9	7	8
7	25	7	11	50	37	1	6	7	14	11	.	4	6	2	3	2	17	10	113	85	79
.	4	4	3	11	8	.	1	1	2	1	.	5	6	7	.	4	22	12	35	21	16
.	.	.	.	.	.	.	.	2	2	2	.	10	11	4	.	33	58	55	60	57	56
1	2	.	.	3	3	.	.	.	.	.	.	30	51	94	8	108	291	201	295	205	204
165	425	98	91	789	541	193	236	417	826	495	41	513	603	790	374	357	2678	1583	5415	3260	2414
95	479	99	103	886	616	193	268	422	863	531	49	543	718	843	405	357	2915	1772	6007	3723	2764

III. REVIEW OF THE PROPORTION,

	I. Carboniferous Period.			II. Trias Period.			III. Oolite Period.		
		Living.			Living.			Living.	
	Total.	Absolute.	Quota.	Total.	Absolute.	Quota.	Total.	Absolute.	Quota.
I. *Plantæ.*	124	0	0	39	0	0	75	0	0
Cellulares	8	0	0	2	0	0	18	0	0
Vasculares	116	0	0	37	0	0	57	0	0
Monocotyledones	101	0	0	27	0	0	39	0	0
Dicotyledones	15	0	0	10	0	0	18	0	0
Monochlamydeæ	12	0	0	9	0	0	15	0	0
Corollifloræ	..	..	..	..	..	..	..	..	..
Choristopetalæ	1	0	0	..	..	..	1	0	0
Dubiæ	2	0	0	1	0	0	2	0	0
II. *Phytozoa.*	146	37	0·25	34	17	0·50	125	69	0·55
Pseudozoa	..	..	..	..	..	..	..	..	..
Amorphozoa	11	3	0·27	7	4	0·59	10	6	0·60
Polygastrica	(1	1	1·00)	..	..	..	..	..	..
Polypi	82	30	0·38	16	8	0·50	70	49	0·70
Foraminifera	7	4	0·57	..	..	..	15	15	1·00
Bryozoa	38	11	0·30	7	2	0·28	24	11	0·46
Anthozoa	37	15	0·40	9	6	0·67	32	23	0·72
Entozoa	..	..	..	..	..	..	..	..	..
Acalephæ	..	..	..	..	..	..	..	..	..
Echinodermata	52	3	0·06	11	5	0·45	45	14	0·31
Stelleridæ	52	3	0·06	9	3	0·33	21	5	0·24
Echinidæ	..	..	..	(2	2	1·00)	22	7	0·34
Fistulidæ	..	..	..	..	..	..	(2	2	1·00)
III. *Malacozoa.*	149	71	0·47	77	58	0·71	157	116	0·74
Tunicata	..	..	..	..	..	..	..	..	..
Brachiopoda	18	4	0·22	7	4	0·57	6	5	0·83
Pelecypoda	51	36	0·70	30	23	0·77	85	67	0·79
Pteropoda	5	1	0·20	..	..	..	..	..	..
Heteropoda	3	0	0	1	0	0	..	..	..
Protopoda	1	1	1·00	1	1	1·00	2	2	1·00
Gasteropoda	54	28	0·52	32	29	0·91	48	38	0·80
(Ctenobranchia	50	25	0·52	27	24	0·89	41	31	0·76
Cephalopoda	17	1	0·06	6	1	0·17	16	4	0·25
IV. *Entomozoa.*	86	11	0·13	9	8	0·10	140	73	0·52
Vermes	14	6	0·43	3	3	1·00	7	5	0·71
Crustacea	64	5	0·08	6	5	0·83	48	11	0·23
Cirripedes	1	0	0	..	..	..	1	1	1·00
Entomostraca	62	5	0·08	2	2	1·00	5	5	1·00
Malacostraca	1	0	0	4	3	0·75	42	5	0·12
Myriapoda	..	..	..	..	..	..	2	2	1·00
Arachnidæ	2	0	0	..	..	..	1	0	0
Hexapoda	6	0	0	..	..	..	82	55	0·67
V. *Spondylozoa.*	103	0	0	37	0	0	119	9	0·08
Pisces	94	0	0	18	0	0	71	3	0·04
Leptocardii, Cyclostomi et Dipnoi	..	..	..	..	..	..	..	..	..
Elasmobranchii	52	0	0	7	0	0	25	3	0·12
Ganoidei	42	0	0	11	0	0	44	0	0
Teleostei	..	..	..	..	..	..	2	0	0
Reptilia	9	0	0	18	0	0	45	6	0·13
Batrachii	..	..	..	..	..	..	..	..	..
Ophidii	..	..	..	..	..	..	..	..	..
Saurii	9	0	0	18	0	0	37	1	0·03
Chelonii	..	..	..	..	..	..	8	5	0·62
Aves	..	..	..	..	..	..	..	..	..
Mammalia	..	..	..	1	0	0	3	0	? 0
Animalia	484	99	0·20	157	93	0·59	541	258	0·4[illegible]
Animalia et Vegetabilia	608	99	0·14	196	93	0·47	616	258	0·42

HE FOSSIL GENERA TO THE LIVING.

IV. Cretaceous Period.			V. Tertiary Period.			I.—V. Periods.			VI. Existing Period.	
	Living.			Living.			Living.			
Total.	Absolute.	Quota.	Total.	Absolute.	Quota.	Total.	Absolute.	Quota.	Sum of all the Living Species.	Proportion of Fossil to it.
36	0	0	189	60	0·32	350	60	0·17	6529	0·009
12	0	0	21	4	0·19	38	4	0·10	718	0·005
24	0	0	168	56	0·33	312	56	0·18	5811	0·010
9	0	0	27	5	0·19	152	1	0·03	1172	0·004
15	0	0	141	51	0·36	160	51	0·33	4639	0·001
9	0	0	57	17	0·30	70	17	0·24	300	0·057
1	0	0	13	6	0·46	14	6	0·43	2280	0·003
3	0	0	57	28	0·49	59	28	0·48	2059	0·013
2	0	0	14	0	0	17	0	0	..	..
199	111	0·58	307	215	0·70	524	242	0·48	652	0·37
1	1	1·00	1	1	1·00	2	2	1·00	13	0·15
26	9	0·35	17	12	0·76	42	15	0·32	15	1·00
7	4	0·57	80	68	0·85	84	69	0·82	168	0·41
105	77	0·73	164	113	0·68	251	138	0·55	245	0·56
38	31	0·82	67	55	0·82	81	59	0·73	77	0·75
40	22	0·55	56	27	0·48	97	33	0·34	75	0·44
27	24	0·89	41	31	0·76	73	46	0·63	93	0·50
..	..	..	..	..	..	..	..	..	60	0·00
1	0	0	3	0	0	3	0	0	75	0·00
59	20	0·34	42	21	0·50	142	28	0·20	76	0·37
15	6	0·40	6	5	0·83	77	8	0·10	36	0·22
44	14	0·32	35	16	0·46	62	18	0·29	29	0·62
..	..	..	1	0	0	3	2	0·67	11	0·18
181	127	0·70	301	274	0·91	473	302	0·64	515	0·59
..	..	..	(1	1	1·00	1	1	1·00)	13	0·08
16	5	0·31	5	5	1·00	29	5	0·07	5	1·00
83	69	0·83	113	104	0·92	174	114	0·65	128	0·89
..	..	..	1	1	1·00	2	2	1·00	2	1·00
..	..	..	..	..	..	4	0	0	9	0·00
3	2	0·67	4	4	1·00	5	4	0·80	5	0·80
62	50	0·81	166	151	0·91	202	167	0·83	221	0·76
54	42	0·78	123	111	0·90	127	126	0·80	138	0·91)
16	1	0·06	6	3	0·50	48	5	0·10	21	0·24
32	20	0·63	516	449	0·87	686	484	0·76	5036	0·09
8	4	0·50	6	5	0·83	21	10	0·48	180	0·06
24	16	0·67	42	34	0·81	165	53	0·32	302	0·55
4	3	0·75	10	10	1·00	13	12	0·92	40	0·30
2	2	1·00	2	2	1·00	70	6	0·09	66	0·09
8	11	0·61	30	22	0·73	82	35	0·43	196	0·18
..	..	..	6	6	1·00	7	7	1·00	40	0·17
..	..	..	53	39	0·74	55	39	0·71	212	0·18
..	..	..	409	365	0·89	438	375	0·85	(4000	0·09)
83	19	0·23	459	257	0·56	731	263	0·36	1311	0·20
69	17	0·25	160	83	0·52	355	87	0·25	496	0·18
..	..	..	..	..	..	..	..	..	6	0·00
26	12	0·46	32	19	0·60	110	22	0·20	66	0·33
8	0	0	12	1	0·08	96	1	0·01	4	0·25
35	5	0·14	116	63	0·54	149	64	0·43	420	0·15
12	2	0·17	43	30	0·70	116	32	0·28	315	0·10
..	..	..	14	7	0·50	14	7	0·50	85	0·08
..	..	..	7	6	0·86	7	6	0·86	105	0·06
11	1	0·09	10	8	0·80	79	9	0·11	100	0·09
1	1	1·00	12	9	0·75	16	10	0·62	25	0·40
2	0	..	55	48	0·88	56	48	0·86	350	0·14
..	..	..	201	96	0·48	204	96	0·47	250	0·38
295	267	0·54	1403	962	0·61	2414	1291	0·54	8232	0·157
531	267	0·50	1592	1022	0·64	2764	1351	0·49	14761	0·090

IV. REVIEW OF THE NUMERICAL PROPORTION

	I. Carboniferous Period.								II. Trias Period.				
	a	*b*	*c*	*d*	*e*	*f*	*g*	Together. *a–g*	*h*	*i*	*k*	*l*	Together. *h–l*
I. *Plantæ.*													
Number of genera .	0	0	21	2	121	15	17	176	0	15	4	26	45
Number of species .	0	0	55	2	879	52	29	1017	0	31	5	62	98
Proportion . . . = 1 :	0	0	2·62	1·00	7·24	3·46	1·70	5·78	0	2·06	1·25	2·38	2·18
II. *Phytozoa.*													
Number of genera .	20	88	68	59	1	1	6	243	24	1	12	2	39
Number of species .	36	223	228	263	1	1	17	769	128	1	19	2	150
Proportion . . . = 1 :	1·80	2·54	3·35	4·46	1·00	1·00	2·83	3·12	5·33	1·00	1·56	1·00	3·85
III. *Malacozoa.*													
Number of genera .	44	62	94	90	35	4	33	362	63	20	44	14	141
Number of species .	260	416	979	809	143	7	94	2708	603	38	109	26	776
Proportion . . . = 1 :	5·91	6·71	10·4	8·99	4·09	1·75	2·85	7·48	9·58	1·90	2·48	1·86	5·50
IV. *Entomozoa.*													
Number of genera .	37	41	31	21	10	0	2	142	1	3	5	1	10
Number of species .	218	264	94	43	18	0	4	641	6	3	12	1	22
Proportion . . . = 1 :	5·90	6·44	3·03	2·05	1·80	0	2·00	4·51	6·00	1·00	2·40	1·00	2·20
V. *Spondylozoa.*													
Number of genera .	0	5	47	21	37	4	19	133	3	10	19	20	52
Number of species .	0	7	110	65	80	7	49	328	4	12	50	77	143
Proportion . . . = 1 :	0	1·40	2·34	3·10	2·17	4·25	2·58	2·47	1·33	1·20	2·63	3·85	2·75
VI. *Animalia.*													
Number of genera .	101	196	240	191	83	9	60	880	91	34	80	37	242
Number of species .	514	910	1311	1180	242	24	164	4445	741	54	190	106	1091
Proportion . . . = 1 :	5·09	4·64	5·88	6·18	2·92	2·66	2·73	5·05	8·14	1·59	2·38	2·87	4·51
VII. *Animalia et Vegetabilia.*													
Number of genera .	101	196	261	193	204	24	77	1056	91	34	80	63	287
Number of species .	514	910	1466	1182	1121	76	193	5462	741	85	195	168	1189
Proportion . . . = 1 :	5·07	4·65	5·26	6·12	5·50	3·17	2·51	5·18	814	2·50	2·44	2·67	4·14
Proportion of separate Classes of Animals.													
Amorphozoa . . . = 1 :	1·00	1·51	1·80	..	..	..	1·64	..	7·33	1	1	1	..
Polypi . . . . . = 1 :	2·23	3·08	3·04	4·00	..	..	2·67	..	2·50	..	1	..	..
Echinodermata . . = 1 :	1·00	1·97	4·55	5·58	1	..	1	..	12·2	..	2·00	1	..
Brachiopoda . . . = 1 :	13·7	11·4	10·1	16·6	..	..	5·00	..	7·17	1·00	3·33	2·00	..
Pelecypoda . . . = 1 :	5·00	3·83	8·20	5·13	5·38	1·75	2·44	..	5·37	2·30	3·09	1·43	..
Gasteropoda . . . = 1 :	2·11	4·32	8·20	8·00	1·46	..	2·00	..	13·6	2·00	2·00	2·80	..
Cephalopoda . . . = 1 :	5·00	10·4	30·0	15·2	10·0	..	1·00	..	14·3	1·00	4·50	..	..
Crustacea . . . . = 1 :	6·30	7·35	3·18	2·31	2·00	..	1·50	..	..	1·00	2·67	..	..
Pisces . . . . . = 1 :	..	1·40	2·34	3·10	2·13	(11·0)	2·80	..	1·33	1·66	3·08	5·80	..
Reptilia . . . . = 1 :	..	..	..	..	1·00	2·00	1·75	..	..	1·00	1·86	2·00	..
Mammalia . . . . = 1 :	..	..	..	..	..	..	..	..	..	..	..	1·00	..

BETWEEN THE GENERA AND SPECIES.

III. Oolite Period.					IV. Cretaceous Period.				V. Tertiary Period.							All the V. Periods.		
m	*n*	*o*	*p*	Together. *m*–*p*	*q*	*r*	*f*	Together. *q*–*f*	*s*	*t*	*u*	*v*	*w*	*x*	Together. *s*–*x*	Sum of *a*–*x*	Sum of I.–V.	True sum.
30	54	1	12	97	0	32	5	37	8	30	115	53	31	0	237	592	463	350
71	152	2	16	241	0	77	7	84	10	136	319	110	48	0	623	..	..	2055
2·37	2·82	2·00	1·33	2·48	0	2·41	1·40	2·33	1·25	4·53	2·77	2·07	1·55	0	2·63	3·47	4·44	5·87
14	122	8	2	144	63	83	184	310	13	115	134	115	117	53	547	1283	811	524
29	579	16	2	626	149	270	1162	1581	35	383	476	502	412	278	2086	..	..	4895
2·07	4·74	2·00	1·00	4·34	2·36	3·25	6·31	5·10	2·69	3·33	3·55	4·36	3·52	5·05	8·14	3·81	6·04	9·34
78	132	66	27	303	116	101	146	363	25	199	218	93	209	146	890	2059	865	473
533	1455	242	102	2332	751	566	1500	2817	39	2125	2725	783	1609	642	7281	..	..	13885
6·83	11·0	3·66	3·78	7·70	6·47	5·60	10·2	7·75	1·56	10·7	12·5	8·45	7·70	4·40	8·18	6·74	16·1	29·3
32	88	2	41	173	16	8	24	42	3	21	134	431	19	6	614	981	783	686
50	256	7	69	382	35	28	114	177	11	85	251	1381	91	9	1828	..	..	2885
1·57	2·91	3·50	1·68	2·21	3·50	3·50	4·75	4·21	3·67	4·05	1·87	3·20	4·79	1·50	2·98	2·96	3·68	4·20
41	83	22	23	169	4	44	63	111	1	178	117	151	29	152	627	1092	801	731
172	278	42	60	552	10	70	161	231	2	367	279	311	110	488	1557	..	..	2701
4·20	3·35	1·91	2·61	3·27	2·50	1·59	2·55	2·08	2·00	2·06	2·40	2·06	3·79	3·21	3·27	2·47	3·37	3·70
165	425	98	91	789	193	236	417	826	41	513	603	790	374	357	2678	5415	3260	2414
784	2568	307	233	3892	945	934	2937	4816	87	2960	3721	2977	2222	1417	13384	..	..	24366
4·75	6·04	3·14	2·56	4·02	4·90	3·95	7·04	11·3	2·12	5·77	6·17	3·77	5·94	3·97	5·00	4·50	7·47	10·1
195	479	99	103	886	193	268	422	863	49	543	718	843	405	357	2915	6007	3723	2764
855	2720	309	249	4133	945	1011	2944	4900	97	3096	4040	3087	2270	1417	14007	..	..	26421
4·38	5·68	3·12	2·42	4·66	4·90	3·77	6·98	5·68	1·98	5·65	5·63	3·66	5·60	3·69	4·80	4·40	7·00	959
..	1·80	..	..	..	3·00	4·17	7·83	..	..	1·33	1·20	4·70	3·00	7·50	..	4·35	6·50	11·0
1	3·25	1·80	..	..	1·93	2·67	6·73	..	1	3·41	3·55	2·08	4·51	1·31	..	3·24	5·78	10·1
2·60	6·27	2·33	..	..	2·65	3·72	5·56	..	1·86	3·64	4·88	1·80	3·39	4·00	..	8·26	11·5	15·4
8·00	16·0	1·50	..	..	7·62	8·67	17·4	..	1·00	4·33	3·00	..	7·67	(4·00)	..	9·88	22·0	39·5
4·71	10·6	4·02	5·92	..	5·51	5·26	10·2	..	1·92	9·16	9·21	4·00	6·54	3·50	..	5·34	13·3	27·7
4·50	7·90	3·31	1·71	..	4·36	4·03	7·98	..	1·33	12·0	16·3	4·27	8·86	4·99	..	7·61	16·9	30·2
19·5	21·6	2·60	..	..	15·1	11·5	14·6	..	1·00	6·00	2·00	..	4·00	..	..	12·1	25·4	32·2
2	3·38	1·00	4·00	..	2·28	2·00	3·31	..	..	2·12	2·71	1·00	5·15	1·50	..	3·32	4·90	5·36
3·94	4·27	2·45	4·78	..	3·33	1·83	2·87	..	..	2·11	2·57	1·74	3·18	(5·00)	..	4·82	6·56	7·61
5·86	1·83	1·36	1·21	..	(1·00	1·00)	1·00	..	..	2·75	2·95	3·37	2·00	2·40	..	2·17	3·02	3·31
1·00	1·50	..	..	..	..	..	..	..	..	1·90	2·00	1·89	6·50	3·32	..	2·65	3·69	3·75

Before deducing from these Tables the palæontological facts which they are intended to exhibit, it is necessary to point out the difficulties which are inherent in such calculations.

It is with the present creation that we desire to compare the creation of each successive epoch; but as yet the examination of existing organisms is imperfect. Cuvier believed that the surface of the earth had been so well explored, that there was little hope of many new species of large animals being discovered; but though it is true that many *very large* species have not been found, the lists of Mammalia, the highest class of animals, have been extended, since 1829, from 800 to 2000 species. The Birds have never been completely described, and the works on Fishes have yet to be finished. Count Dejean has about 30,000 species of Coleoptera alone in his collection,—a number which is so greatly disproportionate to that of the species of other orders of insects in his collection, although in nature they are known to be in nearly equal proportion, as to indicate the still imperfect state of our knowledge as to the totality of insects. And can it be doubted that, were the inquiry extended to every branch of the animal and vegetable kingdoms, the imperfection of our knowledge, even of the present creation, would become still more manifest, and it would be felt that an approximation to the truth is all which we can expect to make?

But there is another difficulty which should be kept in view in comparisons between the past and present creations. In investigating the present conditions of organic and inorganic existence, the inquiry is extended laterally over the surface of the earth, and, as it proceeds, adds continually to the amount of facts which are all related to the one history, namely, that of the earth in its present state. How different is the course of inquiry when directed to the investigation of any former condition of the earth! It is then extended laterally only in a very imperfect and interrupted manner, as the outcroppings of a formation which was once the surface of the earth appear only here and there, the greater portion of it having been thrown down by internal convulsions of the earth, and buried under the matter of succeeding epochs. When, therefore, the Table No. I. states that 514 species of animals have been discovered in the lower Silurian, 910 in the upper Silurian, 1411 in the Devonian, 1180 in the Mountain Limestone, 242 in the Coal Formation, and 24 in the lower New Red Sandstone, and 164 in the Zechstein, whilst in the existing period 101,745 species have been described, it would be erroneous to conclude that the earth of the lower Silurian epoch only supported the $\frac{1}{198}$th part of the number of animals supported by the present earth, and the lower New Red Sandstone less than the $\frac{1}{4000}$th part. On the contrary, if the very limited extent of those portions of the earth's surface of these epochs submitted to our observation be taken into consideration, we shall have reason to feel surprise at the number of species known to us; and when we further consider the numbers of individuals found in some fossil localities, we shall doubtless adopt a far higher estimate of the extent of organic existences in those remote epochs. If, indeed, the number of species found in any geological formation were compared with the extent of surface of that formation known, the estimate would probably in some cases rather exceed than fall short of the numbers of existing organisms: for example, if it were assumed that $\frac{1}{50}$th part of the surface of the earth at the Cretaceous epoch had alone been examined,—an area surely very much beyond the true proportion,—the total number of animals might be estimated at nearly half as much more than the number at present living.

But there is another important difference in the mode of investigation. We know the animals and vegetables of the present creation by the study, with a few exceptions, of living individuals; we know those of past creations by the study of their

dead exuviæ; and in this difference is found an ample explanation of the absence from fossil faunæ and floræ of a multitude of genera, which, from the perishable character of their substance, cannot be expected to leave any permanent relics behind them. The natural habitat of most fossil species indicates the necessity of caution in reasoning on an imperfect fauna, which in our opinion ought not to be ascribed to the absence of certain classes of animals in the fossil epochs, but rather to the improbability of finding their relics in deposits such as those we examine.

A very limited local deposit of the Oolitic period, the Stonesfield slate, gave to light three species of the Marsupial order, an order now of very limited distribution, and thereby brought into strange connection the fauna of that remote epoch with the existing fauna of Australia. If the minute patch which produced so great a scientific treasure be compared with the whole extent of the Oolitic formations already known and studied, how small will appear the chance that such a discovery should ever have been made; and yet this fact is sufficient to demonstrate the truth, that warm-blooded Mammals of the Marsupial order did exist at the Oolitic period; and as the genera belong to the insectivorous type of the order, the fact proved in anticipation that insects must also have existed: and that such was the case has been shewn by the discovery of their relics in the Oolitic strata. Nor is this all; for with Professor Owen we must also assume, that the existence of small quick-breeding Marsupials of an insectivorous type justifies us in believing that the other types of that great order existed also, and that the harmonies of animal life were maintained then as now. Can it, for instance, be doubted that the large carnivorous Marsupials were then in existence, to prey upon the small and quickly multiplying insectivorous species? And such are the remarkable truths brought home to our convictions by the accidental and almost improbable discovery of a few fossil fragments, and which would have remained unknown had not that discovery been made.

It will be observed that the author of the 'Index Palæontologicus' carries back the existence of Mammals to the Keuper or newer member of the Trias; and should such determination be fully established, the difficulty of admitting that no Mammals existed in the Cretaceous epoch is increased, and the inquirer is forced to conclude that the same fortunate chance which gave, as it were, a glimpse at this higher member of the fauna of the Oolites is only wanting to display to us animals of equally high organization in the Chalk. It is, indeed, in the Cretaceous system that the first clear indication of another great class of the animal kingdom is obtained, namely, of Birds; and to this casual and local evidence of a fact so striking the same remarks should be applied, so as to extend its bearing from the simple occurrence of a few relics of two species of birds to the probable existence of other animals in habits and other relations connected with them. It is thus that the fauna of each of these remote epochs may be built up,—speculatively, it is true, but yet reasonably,—from these isolated individuals, just as in the hands of the great Cuvier the whole body of an extinct animal was first restored from the examination of a few of its fragments. Or if we reverse the course of our reasoning, and suppose that the whole of our now existing animals and plants were suddenly annihilated, and, after the lapse of two or three thousand years, Man, having again appeared on the earth, were to endeavour to build up a natural history system of the past epoch from the relics he might discover in distantly scattered portions of the mud and sand-banks of former bays and estuaries, placed within the scope of his observation by the great catastrophe which had accompanied the destruction of organic life,—can we doubt that his task would be most imperfectly performed, and that $\frac{1}{50}$th would be a large proportion to discover of the animals then extinct? Considering, therefore, that the rare occurrence of the fossil relics of Mammals, Birds, Myriapodæ, Spiders, and Insects, should

be ascribed to the improbability of finding them extensively deposited in river, lacustrine, or marine silt, and not to the total absence of such animals from the earth's surface, the numbers representing those animals, or about 74,700 species, may be deducted from the living total, leaving only a total of 27,045 species of recent living animals as the basis of comparison.

This necessary caution in deducing a too general determination of the absolute organic condition of the earth at each geological epoch will be further illustrated as we proceed with those more partial comparisons which are clearly within the power of the Geologist, and which will be here commenced by an examination of Table I.

1. *Carboniferous Period.*—The two great divisions of the Silurian system are characterized in this list by an absence of vegetable fossils; and though this deficiency may in part be accounted for by the metamorphic condition of a large portion of the strata, and cannot be admitted as a proof that no land plants existed, it certainly justifies the Geologist in assuming that these deposits were essentially marine, whilst the character of their fossils indicates some curious peculiarities in their distribution. Taking for example the upper Silurian, in which the fossils are more largely developed, the whole number of animals already known is stated to be 910, or, compared with the reduced number, 27,045, about $\frac{1}{30}$th of the number now living, whilst in some of the great classes the proportion is very different. In the Phytozoa or plant-like animals, the proportion of upper Silurian to the recent, leaving out Entozoa and Acalephæ, is $\frac{1}{14}$th; in the Malacozoa it is about $\frac{1}{28}$th; but this very low proportion may be readily accounted for by the great number of land and freshwater Testacea which form part of the total of recent animals. If, indeed, special classes of this division be selected, the proportion assumes a totally different aspect; as, for instance, the Brachiopoda amount to 148 species, or three times the number of living species, and the Cephalopoda to 94, or about $\frac{3}{4}$ths of the living. If, therefore, the whole of the Silurian world had been fully investigated, in these two classes there would have doubtless been a vast preponderance of numbers in its favour,—a fact of great interest, when the high position of the Cephalopoda in the animal kingdom is considered.

In the Entomozoa, from reasons already stated, the comparison can only be fairly made between the fossil and recent Crustacea, and the proportion of the former to the latter is so high as $\frac{1}{3}$rd, whilst in the Entomostraca the number of fossil species is nearly double that of recent. In fact, the Malacostraca have not as yet been noticed in this ancient fossil fauna; and this apparent deficiency, which occurs, though in a less degree, in all the formations except the Oolite, is very difficult of explanation; but in the latter case, as in the recent fauna, the species of Malacostraca appear to have increased just in proportion to the diminution of those of the Entomostraca, and it is therefore highly probable that the careful comparison of the numbers of each in local faunæ of existing species would afford a clue to the laws which have regulated their distribution. It may be observed that in no other formation is the number of Entomostraca so great, and that the remarkable family of Trilobites distinguishes the Carboniferous epoch from all others, and more especially serves as a guide to the Silurian, to which it has supplied a vast number of genera and species,—for some of which, see Geology Plate VIII. The researches of M. Barrande have thrown additional light on the natural history of Trilobites, and his investigation of the Geology of Bohemia is a striking illustration of their importance for the determination of geological epochs. M. Barrande describes no less than 129 species of Trilobites, which it will be observed is more than half of the number recorded in Bronn's Table; so that even by this one locality it may be presumed that a large extension of the Silurian fauna has been effected,—a conclusion strengthened by the general total of the Bohemian fossils,

which amounts to 600 species, a number nearly equal to half of that given by Bronn. Whilst, however, the number of species of Trilobites is so great, there are but few identical with those previously recorded; and it is therefore from the occurrence of such remarkable genera as Paradoxides, Battus, and Trinucleus, that the identity of formation is determined. In some of the sectional divisions of the Bohemian strata, Trilobites exist abundantly, to the comparative exclusion of other fossils; and this has been partly ascribed to the nature of the water, as being assumed to be more charged with siliceous matter than was suited to the development of Mollusca; but such reasoning appears to be purely speculative. At the Silurian epoch, as at the present, the several peculiarities of the sea-coast, its bays and estuaries, must have influenced the character of its organic inhabitants; and whilst in muddy bays and seas giving rise to the geological formation of slates, multitudes of Crustacea may have lived, there can be no doubt that Cephalopoda and Mollusca were equally flourishing in other portions of the same sea, where the physical conditions were more in conformity with their vital necessities. The relics of large Cephalopoda and of many of the Brachiopoda would be naturally sought for in those deposits which had been formed in the regions where they peculiarly existed; and it is therefore in deep sea deposits, or in the massive limestone strata, that they are principally found. In Plate VIII. some of them have been figured. It may be safely laid down as a rule, that the occurrence of Trilobites in abundance is strong presumptive evidence that the strata belong to the Silurian epoch, and if they can be allocated to any of the well-known genera of that formation, all difficulty of determination is removed. In the calcareous deposits, some of which have doubtless been contemporaneous with the slaty, the Cephalopoda, Brachiopoda, and Zoophytes will afford a clue to the identification of the strata nearly equally decisive, though not so easy and striking. The late discovery by Mr. Salter of a Silurian Chiton is a remarkable fact, as tending still further to place the ancient fauna in harmony with the recent.

c. Devonian.—This formation, so remarkable for its sandy, pebbly, marly and schistose deposits, occupies a transition place between the Silurian and true Carboniferous formations, and is often therefore difficult of determination. The condition of the Silurian Crustacea found in this formation is sometimes such as to indicate their exposure to attrition, and consequently to induce a belief that they are not *bonâ fide* Devonian fossils. The total number of species of animals has increased to 1411, and whilst the Crustacea, so strikingly characteristic of the Silurian, have diminished from 257 to 86, the gasteropodous Molluscs have risen from 71 to 246, and the Cephalopoda from 94 to 270,—so as to more nearly resemble in distribution the true Carboniferous than the Silurian fauna. The Devonian has, however, its own peculiar characteristic in the richness of its Ichthyology,—no less than 110 species of fishes having been recorded at the date of the Index. The local nature of the marly or clayey beds in which the remains of fishes might be preserved renders it rarely possible to use them for stratigraphical identifications, and dependence therefore must principally be placed on the Mollusca. (See Plate IX. 'Geology.')

d. Mountain Limestone and Coal Formation. — These two divisions constitute the true Carboniferous system, the two members of which exhibit very striking peculiarities. In the Mountain Limestone, the Brachiopoda number no less than 199, many of which are strikingly characteristic, whilst the Coal strata have only 4,—and generally the Mollusca in the former number 809, and in the latter only 143. The great peculiarity of the Coal series is, however, the richness of its flora, which, coupled with the almost total absence of the Phytozoa, and the appearance, for the first time, of reptiles of the Saurian type (Archigosaurus Decheni), can leave little doubt on the mind that the conditions of deposit were very different from those of the Mountain

Limestone. The one has every characteristic of a deep sea deposit, the other of estuary and almost lacustrine deposition. Göppert has shewn that the formation of coal may be imitated mechanically, and has noticed this curious distinction, namely, that by operating on the vegetable structure alone, substances analogous to the brown or tertiary coals are produced, whilst by adding sulphate of iron a true coal is the result. This distinction points to a peculiarity in the vegetables which gave rise to the coal deposits, and justifies him in his opinion that the sulphuret of iron so common in the beds of coal proceeded from the plants which produced them. Sigillariæ, Lepidodendra, and Calamites are characteristic of the true Coal formation.

The frequent occurrence of the genus Cypris in the shales of the Carboniferous system is also strongly illustrative of the manner of their formation.

f. g. Permian System, comprising lower New Red Sandstone and Zechstein or Magnesian Limestone.—This section of the New Red Sandstone is placed by Bronn in the Carboniferous system, and in this opinion many Geologists concur, as the fossils of the Magnesian Limestone exhibit a great similarity of character, more especially in the occurrence of the genera Productus and Spirifer. In the marly beds of the Sandstone many fishes have been found, and there is still a considerable proportion of plants. In the Magnesian Limestone section the total number of fossils is much greater than in the lower Red Sandstone, but whilst it has contributed seven times the number of animals to its fauna, it possesses scarcely more than one-half the number of plants. This great difference is strongly marked in the Malacozoa, the Magnesian Limestone having produced 94 species, and the Sandstone only 7; but there can be little doubt that this absence of fossils from the sandy strata is the result of their disintegration, such deposits being peculiarly unfavourable to the preservation of organic remains. Between the Mountain and the Magnesian Limestones the Tables exhibit one very marked difference, namely, the abundance of Echinodermata in the former (some of which have been figured in the Plates to 'Geology') and their comparative absence in the Magnesian. The great development in Russia of this geological section has led to the adoption of a distinct name for it,—the Permian system,—but whilst the great similarity of its fossils closely associates it to the Carboniferous, it should be remembered that the occurrence of carbonate of magnesia is only the result of the greater development of a mineral which often enters into the composition of the Mountain Limestone. The greater number of reptiles is perhaps sufficient to indicate a difference in the conditions of deposit, more especially when combined with the deficiency of Echinodermata; but that there is more analogy between the Permian and Carboniferous epochs than between the Trias and Permian may be further proved by reference to the fauna of the Trias, which assuredly in the Muschelkalk approaches to the character of the Oolitic fauna, just as that of the Zechstein approaches to the Carboniferous. And were any further proof required, it is found in the floræ of the successive epochs, that of the Permian being, like the Carboniferous, distinguished by the predominance of Ferns and Lycopodiaceæ, whilst the Trias, like the Oolitic epoch, abounds in Cycadeæ and Coniferæ.

h, i, k, l. Trias Period.—Leaving out of immediate consideration the St. Cassian Beds (*h*), which, as Bronn states, are only local, although they produce a sea fauna of probably more species than could be collected in a similarly limited space of our present sea bottom, the Trias exhibits a remarkable diminution in its organic contents. To account for this defect, it has been supposed that the great amount of oxide of iron was injurious to organic and more especially to animal life; but such a theory places a co-existing effect in the position of a cause. All sandy beds must be unfavourable for the preservation of organic remains, as the ready filtration of water charged with carbonic acid must promote their rapid disintegration; and indeed, in this man-

ner all the solid parts of many fishes have disappeared, although the impressions of their external coverings or scales remain as distinct as if they had been drawn from life. The frequent association, also, of gypsum in large quantities with the salt-beds of this formation may also suggest other causes;—its occurrence is not improbably of secondary origin. In England, the Muschelkalk is only very faintly represented, if it exist at all, but on the Continent it forms the central member of the formation. By the occurrence of the ammonitic type of Cephalopoda it approximates to the next period, and it may well be doubted whether a formation in which arenaceous beds so strongly predominated should be kept distinct, as such a character bespeaks a partial origin, and indicates a portion rather than a whole. It is well known that the footsteps of a remarkable animal long noticed on the beds of the New Red Sandstone have been traced to the Labyrinthodon, a reptile between the Saurian and Batrachian types, whose remains have been found in the Muschelkalk; but the recent discovery of similar footsteps in Pennsylvania, in strata considered of the age of the Old Red Sandstone, will carry the origin of reptile life up to that remote epoch, should the determination of the age of the deposit prove correct. Mr. Lea has called the animal of which these footsteps are as yet the only records, Sauropus primævus. The Chelonians or Tortoises appear for the first time in the list, affording another analogy with the Oolitic period. The flora, according to M. Adolphe Brongniart, affords a more certain element of comparison, as it no longer, like the Permian, exhibits strong analogies with the Carboniferous, but differs from it in a marked manner.

That distinguished botanist points out that two causes of difference must be admitted in fossil floræ, the one due to change of epoch, the other to difference of geographical position,—just as in the present time there are local variations, a forest of Pinus sylvestris growing in Germany, one of Abies taxifolia in the Vosges, of Picea excelsa in the Jura, and of Pinus pinaster in the Landes. This is very evident in the flora of the Permian system; but though the local floræ of the epoch were specifically varied, they possess a common relation to the flora of the Coal formations, of which they appear to be an extract. Turning, however, this point, a great botanic change takes place, and the Trias and Oolitic periods are linked together by the prevalence of plants belonging to another great division of the vegetable kingdom, the Gymnosperms. This difference in the floræ of successive epochs, and the equally striking differences between the fossil and recent floræ, should be sufficient to satisfy even those who still hesitate to receive the evidence which Geology affords of extinct worlds. Brongniart, for example, states that the Coal formations of Europe have as yet produced only 500 species, whilst the flora of Europe includes about 11,000; but if the Ferns of the two periods be compared, the disparity is in the other direction, as the Coal formation of Europe has already produced 250 species, and the whole of Europe now only produces 50. When, therefore, this difference in arrangement is combined with the variation of form, also so manifest, is it possible that even the most sceptical on geological truths can persevere in attempting to consider all these extinct organisms as only portions of the existing creation? In Plate X. of 'Geology' some of the most remarkable fossils of the Trias are figured. As this is, as it were, the turning-point from the more ancient organic condition of the earth's surface, it may be well to abstract briefly some of the conclusions of Mr. W. King in his recent Monograph of Permian Fossils. The genus Productus, so characteristic of the fauna of the Carboniferous epoch, and well exhibited in the Permian, appears also in the marls of St. Cassian,—so that some doubt may be felt as to the age of the latter. In the Permian system, remains of the tetrabranchiate division of Cephalopoda, or of the Cephalopoda with external shells and internal siphons, have alone, as yet, been found; whereas Rhyncolithes, or the man-

dibles of Cuttle-fish, or of dibranchiate Cephalopoda, occur in the Trias, and thus prepare the way for the Belemnites of the Lias. This commencement (Bellerophon is of doubtful analogies) of a great series of remarkable animals, which in the existing epoch comprises so many genera and species (our Sepia, Loligo, Argonauta, &c.), deserves especial attention, and should be always compared with the almost evanescent condition of the other great branch, the tetrabranchiate, now represented by only two species of the single genus Nautilus.

There are, however, many difficulties in settling the exact zoological relations of strata, standing as these do on the limits of two great divisions. The absence of Trilobites from the Permian rocks is a strong negative difference between them and the Carboniferous; but this may be in great measure ascribed to difference of physical conditions. In the Fishes there is a close generic though not specific connection between the Permian and Carboniferous, whereas the approximation is very much less between the Permian and Triasic. In the Reptiles, as yet, the comparison can only be considered imperfect; as the impressions of supposed Labyrinthodonts have been noticed by M. Conrad in the Devonian system of the United States, and should the determination be verified, the reptile character of the Trias will be bestowed on rocks of a more ancient date even than the Coal, as it is to a certain extent on the Coal series itself by the labyrinthodont forms (as they are considered by Von Meyer) of Archigosaurus and Sclerocephalus. On the whole, we are disposed to adhere to the arrangement of the Tables, and to consider the Permian a portion of the Protozoic, the Trias a portion of the Deuterozoic period, as the appearance of the ammonitic forms of Cephalopoda in the Trias is of itself a powerful argument for approximating it to the Oolitic rather than to the Carboniferous system; far more powerful than the continuance of a few forms of the preceding epochs would be for the opposite determination.

m, n, o, p. *Oolitic Period.*—This great member of the Deuterozoic formations is replete with objects of the highest interest. It has been already stated that, leaving out of consideration the recently supposed occurrence of Mammals in the Keuper, the Oolitic formation has produced the first Mammalian relics, exhibiting at this early epoch examples of the Marsupial type which is now so characteristic of Australia,—a region widely distinguished both by its fauna and flora from other parts of the known world. And when to this strange fact is added the records which Palæontology affords of its numerous reptiles, the fish-like Saurians (Ichthyosauri and Plesiosauri), and the flying Saurians (Pterodactyli), we are prepared to study and admire a rich and varied but most strange assemblage of organic bodies. The beaks of supposed dibranchiate Cephalopoda have been noticed as occurring in the Trias, but with the Oolites they enter distinctly into the fauna and afford examples of seven genera, one of which extends into the Chalk, another reappears in the Tertiaries and extends into the recent epoch, and four more, after apparently disappearing with the Oolites, reappear in the recent epoch. Of all these none is more remarkable than the genus Belemnites, which affords a close link of connection between the Oolitic and Cretaceous formations, just as the Trilobites and Producti of the Protozoic period did between the Silurian and true Carboniferous. M. Alcide D'Orbigny divides the genus into three sections, each characteristic of a geological division; namely,—1. Those with neither ventral nor lateral grooves, which are peculiar to the Lias or lower section of the Oolites; 2. Those with a ventral but not with lateral grooves, which belong to the upper Oolitic sections; 3. Those with a ventral and two lateral grooves, which belong to the Neocomian (or lower greensand) and gault sections of the Cretaceous formation. Of the Belemnites of the white or upper Chalk, M. D'Orbigny forms his sub-genus Belemnitella, which is characterized by

an anterior notch, so that the species of this remarkable family have changed in form and character in the successive faunæ of the earth, and after having swarmed in such abundance during the Oolitic and Cretaceous periods, have totally disappeared with the latter from its surface. The changes which have taken place in the tetrabranchiate division of Cephalopoda are also most remarkable.

These Cephalopoda are divided by D'Orbigny into two great families; 1st, Nautilidæ; 2nd, Ammonidæ. In the first, D'Orbigny recognizes the genera Nautilus, Aganides (Clymenis), Cyrtoceras, Lituites, Orthoceratites. All these appeared in great numbers and in very varied forms (including Phragmoceras) in the ancient fauna of the Silurian epoch; but, strange to say, the genus Nautilus alone occurs in the Oolitic and Cretaceous. The Aganides reappear in the Tertiary, but the genus Nautilus alone preserves to man a knowledge of the tetrabranchiate Cephalopoda of ancient worlds. The Nautilidæ are distinguished from the Ammonidæ by the straight or simply arched septa of their chambers, those of the Ammonidæ being lobed or digitated, and by a central or medial siphuncle, that of the Ammonidæ being dorsal (more properly called ventral).

The family of Ammonidæ contains seven genera, one of which only, namely, Goniatites, goes back so far as the carboniferous strata, of which it is a characteristic Cephalopode, at once appearing and ending in them. As the Goniatites have their septa formed with either angular or rounded lobes, and not with lobes of the foliated forms of the Ammonidæ, they are very distinct from them, though associated in the same family. With the Muschelkalk true Ammonites begin, though still with comparatively simple septa, but in the Oolites they attain highly digitated or ramified septa, and exhibit a number of species, these animals having been peculiarly abundant at this epoch. It is scarcely necessary to refer in detail to other animals, though the genera Lima and Gryphæa are highly characteristic amongst the bivalves, and the genus Trigonia, now existing only in Australia, occurs to confirm, as it were, the analogies already established by the presence in the Oolitic strata of Marsupial Mammals. In the whole series of ancient creations, none is more remarkable than the Oolitic, and it has been called, from the peculiarly rich development of its reptiles, the age of reptiles. The great marine Saurians, Ichthyosaurus and Plesiosaurus, have been already noticed, genera which seem to form a link between reptiles and fishes, and, as Professor Owen states, between reptiles and cetaceous mammals; but in addition to these, reptiles of the true crocodilian type appear at this epoch. Some of these, Teleosaurus, Steneosaurus, Cetiosaurus, were, like the Gavials, fitted to prey on fishes, having long narrow jaws armed with slender, conical, sharp-pointed, and equal teeth: they were indeed mighty monsters, the jaws of the Teleosaurus Chapmanni exhibiting at least 140 teeth, and the bodies of some of the species of the two first genera being 18 feet long, whilst in the third genera some of the species attained an enormous bulk, the Cetiosaurus medius having possibly been 40 feet long, and others having almost rivalled the modern whales in magnitude. Passing, however, from the marine, only remarking that Saurians with true marine habits are now represented by only one species, the puny Amblyrhynchus of the Gallipagos Islands, we find that the land was equally replete with wondrous exhibitions of these gigantic reptiles, forming the Dinosaurians of Owen, which are called by him Crocodile-lizards, being distinguished both from the modern terrestrial and amphibious Sauria, and from extinct marine lizards. Of these the most remarkable are the Megalosaurus, the Iguanodon, and the Hylæosaurus. Professor Owen corrects the preceding estimates of the length of the Megalosaurus, which he considers excessive, and reduces it to 30 feet; but even this is sufficient to constitute an enormous creature, more especially as it was more elevated and bulky

than ordinary Saurians, and resembled in character the large terrestrial mammalian quadrupeds of the present epoch. Of British Oolitic strata, the Stonesfield slate, Bath oolite, Cornbrash, and Wealden have produced specimens of this genus. The Hylæosaurus and Iguanodon are both from the Wealden, the latter having been discovered by Dr. Mantell, and called Iguanodon by Conybeare from the resemblance of its teeth to those of the living Iguana, though in other anatomical characters it is strongly distinguished from it. From the supposed analogies between this reptile and the Iguana, it was estimated that the Iguanodon might be from 75 to 100 feet in length, but Professor Owen, on apparently sounder principles, deduces the length of 28 feet, a magnitude still entitling it to the appellation of enormous reptile. A consideration of this wonderful group of animals must fill the mind with admiration at the creative intelligence and power of the Supreme Originator of all things. This extraordinary development of reptile forms has been ascribed to a defective condition of the atmosphere, but, although the existence of land mammals negatives such a supposition, there appears to be reason in the opinion of Professor Owen that these gigantic reptiles may have supplied the place of the large predaceous mammals of the present world. Be this, however, as it may, the Oolitic fauna,—with its Marsupials associated with the genus Trigonia of conchiferous Molluscs, (as at the present epoch they are in Australia, the land of Marsupials,) with its Belemnites and Ammonites, many of large size, its insects, and above all with its gigantic reptiles, which people the land, the sea, and the air,—must always be distinguished amongst the records of extinct worlds, for its singularity and grandeur.*

q, r, f. Cretaceous Period.—Although the mind must long linger with delight on the extraordinary fauna which the Oolitic period has placed before it, the interest which the Cretaceous fauna is calculated to excite is of no ordinary kind. It is here that the remains of Birds are first distinctly recognizable in the Cimoliornis Diomedeus, or long-winged bird of the Chalk; a fact which from the imperfection of the specimens could only have been established by the anatomical skill of Owen, who considers that the bird approaches nearest to the Albatross, though probably greatly exceeding it in size. As in the case of the scanty remains of Mammals discovered in the Oolite, the occurrence of even one specimen of a bird of recognizable type must be accepted as sufficient evidence of a more complex and complete fauna than could be inferred from the remains of aquatic animals alone, and the rarity of such specimens needs no other explanation than the marine nature of the deposit in which they occur. In the genera Mososaurus, Leiodon, and Raphiosaurus, the Lizard-Saurians are represented, and Professor Owen states that below the Chalk he has not hitherto found any instance of a reptile possessing vertebræ with an anterior cup and posterior ball, or the ordinary ball and socket structure of existing species. Chelonians (Turtles and Tortoises), which commenced in the Triasic and appeared also in the Oolitic period, occur in the Chalk, though not noted in the Table. They are referred by Professor Owen to the marine section, or to the true Chelone.

Referring now to the Cephalopodous Molluscs as the most characteristic of both the Oolitic and Cretaceous periods, the Belemnites are continued from the Oolites in the two genera Belemnites and Belemnitella, the latter being characteristic of the upper Chalk. In the Tetrabranchiate division, the genus Nautilus produces a considerable number of species, and D'Orbigny gives as a characteristic difference between those of the Oolitic period and those of the Cretaceous, that in the former there are

* Dr. Mantell has recently discovered portions of a terrestrial Saurian, which he considers distinct from those previously described in the Oolitic strata. He calls it Pelorosaurus, or Monster Saurian, and estimates its length at about 80 feet.

never deep transverse furrows, so that any specimen of Nautilus exhibiting transverse furrows or ribs, may be, with every probability, assumed to be cretaceous. Of the *family* of Ammonidæ the first trace had been observed in the Goniatites of the Carboniferous strata, but in the Muschelkalk (a member of the Trias) true Ammonites began to appear, and in the Oolitic period attained their highest development in numbers and variety of form. In the Cretaceous epoch they exhibit a variety and profusion nearly equal to that of the Oolitic, and are combined with several other generic forms of the ammonidic type, such as Hamites (which appeared first in the Oolitic period), Crioceratites, Scaphites, Baculites (which being, as it were, straight Ammonites, represent the Orthoceratites, or straight Nautili of the more ancient epoch), and Turrilites. D'Orbigny, in his 'Paléontologie Française,' has figured no less than 143 species of the genus Ammonites from the Cretaceous strata, so that the richness of the fauna of that epoch in such Cephalopoda is truly wonderful, and strongly contrasted with the poverty of our recent fauna.

It is of the highest importance to understand the actual geological distribution of Ammonites, as they are assuredly the most characteristic fossils of both the Oolitic and Cretaceous periods, and for this purpose it is desirable to study the classification of Von Buch, as improved by D'Orbigny.

1. Von Buch considers the Goniatites as a section of Ammonites, but they may be left out of the present inquiry, as the simply rounded and angular lobes of their septa at once distinguish them from all true Ammonites.

2. He places the Ammonites of the Muschelkalk or Trias in a separate section—the Cératites—as their septa, being much more simply lobed than in the subsequent sections, point them out as an intermediate group.

Species with one entire or simple dorsal (more properly ventral) keel.

3. *Arietes:* shell marked on the sides by simple radiating projecting ribs; back square, with a central keel; siphon prominent, placed on the dorsal keel; mouth prolonged into a beak; septa formed of uneven lobes and swells (saddles of Von Buch); dorsal lobe as deep, as wide, and longer than the upper lateral lobe: the lateral swell ascends higher than the others, and the dorsal swell is very short. This group is peculiar to the lower portion of the Lias.

4. *Falciferi:* shell compressed, having on the sides folds inflected forwards, and often forming an elbow in the middle of their length; no tubercles; back sharp, extending into a narrow keel which contains the siphon; mouth complete, having projecting points in the centre of each side; lobes of septa uneven; swells nearly even; dorsal lobe very wide, and its accessory lobe may be taken as the upper lateral, and is always much longer than the dorsal lobe. This group is peculiar to the upper beds of the Lias.

5. *Cristati:* shell compressed, and adorned on the sides by bifurcated ribs, which are inflected forwards, but do not form an elbow; with or without tubercles; back extending into a keel which contains the siphon; mouth perfect, prolonged into a central beak; septa formed of lobes which are generally divided into uneven parts, and of even swells; dorsal lobe larger than the upper lateral; lateral swell less elevated than the rest; dorsal swell very high. This group is peculiar to the Cretaceous period.

Species with a channeled back.

6. *Tuberculati:* shell adorned on the sides with ribs and with tubercles which alternate on the sides of the back; back provided with a deep central channel; mouth complete, representing an elongated beak which corresponds to the dorsal canal; septa formed of lobes and swells divided into uneven parts; dorsal lobe shorter than the upper lateral lobe, and so narrow that it does not occupy the

breadth of the dorsal canal. All the species of this well-defined group belong to the Cretaceous period.

Species with sharp backs not keeled.

7. *Clypeiformi* (D'Orbigny): shell compressed, generally smooth or very slightly ridged; back sharp or wedge-shaped, but without keel; whorls of spire large, and generally enveloping; septa divided into a great number of lobes formed of unequal parts and of swells formed of equal or nearly equal parts; dorsal lobe shorter than the upper lateral lobe; both swells and lobes wide and short. This group belongs to the Cretaceous period.

Species with the back projecting, and notched along the medial line.

8. *Amalthei:* shell ribbed on the sides, the ribs being slight and inflected forwards; the back sharp, and divided by transverse plaits or folds which form a notched surface; mouth provided with a central beak, the ancient condition of which may be traced in the notches on the back; septa formed of lobes and swells divided into uneven parts; dorsal lobe shorter than the upper lateral lobe. This group is peculiar to the Jurassic and Oolitic beds.

9. *Pulchelli* (D'Orbigny): shell elegantly marked on the sides by straight (not inflected) projecting ribs, which extend from one side to the other, forming on the back a compressed tubercle, so as to produce a series of crests, resembling cocks' combs; septa composed of lobes divided into uneven parts and of swells divided into even parts; dorsal lobe nearly equal in length to the lateral inferior one. This group belongs to the lower Cretaceous strata, the lower greensand and gault.

10. *Rhotomagenses* (D'Orbigny): shell with swollen square or oval whorls, which are adorned by projecting ribs, more or less tuberculated, the tubercles being arranged in four or five rows, one of which occupies the medial line of the back, and renders it more or less angular; septa formed of lobes and swells divided into equal parts; the dorsal lobe longer than the upper lateral lobe. This group differs from the Armati by having several rows of tubercles along the back, one of which is medial, by its equal lobes, and by its dorsal lobe, which is always the longest. All the species belong to the upper greensand of the Cretaceous epoch.

Species having a hollow back and tubercles on the sides.

11. *Dentati:* shell more or less smooth, adorned with ribs which are often bifurcated at the margin of the umbilicus, where they usually form tubercles: the ends of the ribs project on each side of the back, the middle of which is hollow; septa formed of lobes divided into unequal parts and of swells generally divided into equal parts; dorsal lobe equal to or shorter than the upper lateral lobe. All the species of this group belong to the lower portion of the Cretaceous system, viz. the lower greensand and gault.

12. *Ornati:* shell slightly swollen, with narrow back, bordered by tubercles; another row of tubercles at the depression of the spire towards the middle of the flanks; septa formed of lobes and swells composed of unequal parts; the dorsal lobe very much shorter than the upper lateral. A group exclusively belonging to the Oxford clay, a division of the Oolitic formation.

Species with the back more or less square.

13. *Flexuosi:* shell furnished laterally or at the margin of the umbilicus with a row of tubercles, and with another at each side of the back, the middle of which forms a slight projection. Between the two rows of tubercles of the sides are generally ribs which are slightly inflected forwards; septa formed of lobes divided into unequal parts and of swells divided into equal parts; the dorsal lobe shorter than the upper lateral one; the upper lateral very wide. A group belonging to the lower portion of the Cretaceous system.

14. *Compressi* (D'Orb.): shell generally very compressed, composed of large whorls closely enveloping each other, and having lateral ribs or striæ which are only slightly inflected, and form tubercles on the sides of the back; back narrow and square, as if truncated; septa composed of a great number of lobes divided into unequal parts and of swells frequently formed of equal parts; dorsal lobe very great, being much longer than the upper lateral lobe. A group belonging to the Cretaceous period, and extending over the whole of the greensand.

15. *Armati:* shell with square whorls, having on the sides of the back one row of projecting tubercles, and on the flanks one or more rows; back wide and square; septa composed of lobes formed of unequal parts and of swells formed of equal parts; dorsal lobe longer than or equal to the upper lateral lobe, the latter being placed in the middle of the flanks, and always narrow as regards the dorsal swell. A group peculiar to the Oolitic period, and specially to the upper members of it.

16. *Angulicostati* (D'Orb.): shell thick, with whorls almost round, though marked on each side of the back by a slight projection which renders this part nearly square; back much more narrow than the flanks; the ribs elevated, and alternately passing over the back from one side to the other; septa composed of lobes formed of unequal parts and of swells generally even: the dorsal lobe is much shorter than the upper lateral, and the auxiliary lobes are oblique towards the umbilicus. A group belonging to the lower portion of the Cretaceous system, and differing from the Planulati only by the square back.

17. *Capricorni:* shell with very convex whorls, adorned by bold simple straight ribs without tubercles or spines; back wide, often having a surface more extensive than that of the flanks; septa composed of lobes formed of unequal and swells of equal parts; dorsal lobe the largest; the lateral lobes wide. A group peculiar to the Oolitic period.

Species with rounded convex back.

18. *Heterophilli* (D'Orb.): shell compressed, formed of whorls which are almost always so far enveloping as to be rarely visible in the umbilicus: the sides are smooth, slightly striated or grooved; back narrow, and very convex; septa symmetrical, divided into a great number of highly ramified lobes, the parts of which are uneven, and of swells generally composed of equal parts; dorsal lobe almost always shorter than the upper lateral lobe. From the great number of branches of the lobes, the swells between them represent the form of leaves in a very striking manner. This group extends from the Oolitic period into the Cretaceous, but it admits of subdivision according to the unequal or equal parts of the swells; and whilst the former section belongs exclusively to the Oolitic, the other is equally peculiar to the Cretaceous.

19. *Ligati* (D'Orb.): shell compressed, generally smooth or only slightly waved, and usually marked at intervals by grooves or ribs which formed the margin of the mouth at its successive stages of growth; back convex, sometimes a little compressed; septa composed of lobes formed of unequal and of swells of generally equal parts; the dorsal lobe shorter than the upper lateral; the last auxiliary lobes often oblique to the rear on approaching the umbilicus; the swells very divided, but never resembling leaves. A group peculiar to the Cretaceous period, and extending over the lower and upper greensand.

20. *Planulati:* shell discoidal, compressed, composed of whorls more or less cylindrical, adorned with striæ or crowded ribs, which towards the middle or at about two-thirds of the flanks divide into several branches, though not provided with knobs at the point of junction; back round; septa composed of lobes always divided into uneven parts and of swells usually formed of even parts; the dorsal lobe either longer or

shorter than the upper lateral: the auxiliary lobes are obliquely directed backwards towards the umbilicus in a marked manner. A group which would be peculiar to the Oolitic period, were it not that three species of the lower Chalk, of which the lobes are only imperfectly known, are provisionally included in it.

21. *Coronarii:* a group which specially characterizes the lower Oolite. It is distinguished from the Planulati by having a knob or tubercle at the point where the ribs or striæ bifurcate; whorls elevated; septa composed of lobes divided into unequal and of swells formed of equal parts; the dorsal lobe shorter than the upper lateral; the auxiliary lobes oblique: the upper lateral lobe is outside of and the inferior lateral lobe within the tubercles.

22. *Macrocephali:* shell analogous in form, ribs or striæ, to that of the group Coronarii, with this difference, that it is often more swollen, and the tubercle, instead of being placed about the centre of the breadth of the whorl, is nearer the umbilicus, so that both the upper and lower lateral lobes are outside the tubercle, and not one within and the other without. The most swollen species proceed from the Oolitic strata, but the group itself extends into the Cretaceous.

23. *Fimbriati* (D'Orb.): shell discoidal, composed of cylindrical whorls which are generally contiguous, without in any manner covering each other, and are either smooth or transversely marked at intervals by projecting ribs or by grooves which were the former margin of the mouth; mouth circular; septa symmetrical, formed of lobes and swells divided into equal parts, and always enlarged at their extremity and narrowed at their base; dorsal lobe often the longest. This group, so well characterized, is found both in the lower portions of the Oolitic and of the Cretaceous periods: the greater number of species belong to the lower greensand, or base of the Cretaceous system.

It has appeared desirable to give these ample details on the highly important genus Ammonites, as it will often be necessary, in geological researches, to seek the means of identification of strata in the several groups into which it is divisible, as in many cases those mineral differences which may assist in such inquiries, and are in some localities or countries well marked, disappear entirely in others. With the Chalk, Ammonites disappear, the upper section of the white chalk being deprived of them. In this interesting and varied family, therefore, of the most highly organized class of Mollusca (the Cephalopoda), each successive fauna of the earth's surface possessed characteristic representatives, commencing with the Goniatites of the Carboniferous strata; and so beautifully, nay, so mysteriously has this great law of creative intelligence been manifested in the distribution of organic bodies, that D'Orbigny recognizes even characteristic species in his three divisions of the Cretaceous system, assigning

75 species to the Neocomien, or Lower Greensand.
42 do. to the Gault.
27 do. to the Chalk, including the upper Greensand and true Chalk.

And so striking is this limitation of the species to particular faunæ or epochs, that he thus remarks upon it: "After comparing thousands of these Ammonites from all parts of France, I have come to this important result, that it is not merely some species, as has been hitherto supposed, which are characteristic, but that all the species of Ammonites, without exception, are characteristic, and that all indicate with certainty the strata to which they belong, when the application of their evidence is made with a critical knowledge of the species."

To the Ammonites may be added other remarkable genera of Cephalopoda which are peculiar to the Cretaceous period:

Crioceras, differing from Ammonites in having the whorls, though in one plane, perfectly separate from each other, and not contiguous or enveloping. The lobes of

their septa are always formed of unequal parts. D'Orbigny describes seven species, five of which are peculiar to the lower greensand, and two to the gault, the genus itself having had therefore a very limited range of existence.

Toxoceras, differing from Ammonites, as the whorls do not form a spiral, but are arranged like an oblique horn. D'Orbigny describes nine species, which all belong to the lower greensand, to which the genus appears restricted.

Scaphites: shell in the early stages of growth resembling Ammonites by its contiguous whorls, but then suddenly extending in a straight line for a considerable distance, when it is again bent back towards the spire. This genus only existed during the deposition of the upper and lower greensand, and D'Orbigny reduces the known species to three in number.

Hamites, separating from it those species which form the genus Ancyloceras (D'Orb.), is peculiar to the Cretaceous epoch, beginning with the lower greensand, abounding in the gault, and disappearing in the upper greensand. It is distinguished from Ancyloceras by having an irregular spire composed of elliptical whorls bent round, as it were, in elbows. The whorls are in the same plane, are never in contact, and are prolonged at each turn for some distance in a straight or curved line, and then again bent round, so that at the final turn the last elbow appears disconnected with the spire.

The shell of the genus *Ancyloceras* begins with a regular spire, the whorls of which are not in contact, as in the Scaphites, but are finally continued, as in them, for some distance in a straight line, and terminated by an elbow or cross. It commences with the lower oolites, and ends in the lower greensand,—not having been as yet discovered in the intermediate strata.

Ptychoceras: shell not spiral, but resembling a round or compressed siphon or tube bent back upon itself, so that the last turn is close to and connected with the first, appearing therefore, in a young state, as if straight. The septa are symmetrical, regularly divided into six slightly unequal lobes. The genus is confined to the lower greensand.

Baculites are straight Ammonites, the shell being either regularly conical, slightly compressed, or angular, like a straight horn, the upper portion being for a considerable space without septa, and the mouth furnished with a dorsal projection or beak, like some Ammonites. The septa are more simple than in the Ammonites, having only four lobes. The Baculites are peculiar to the Chalk period, which they therefore characterize.

Turrilites. In these chambered shells the spire is obliquely whorled, so that it resembles an ordinary turbinated univalve shell. The whorls are either round or angular, and contiguous. The whole spire is umbilicated. This genus commences in the upper gault, and only extends to the upper greensand.

Helicoceras (D'Orb.). The shell resembles that of the Turrilites, but has its whorls disconnected. The genus has only been discovered in the gault.

This truly wonderful variety of form in the family of Ammonidæ, exhibited in a manner so marked, excites in the mind a feeling of intense admiration, as it would almost appear that creative intelligence had exhibited this power of adapting the shapes of other shells to the habitations of cephalopodous Molluscs, in order to stamp upon the Cretaceous fauna a character of peculiarity which equally separates it from that of preceding and of subsequent epochs.

In respect to other classes our remarks will be but brief, though sufficient to support the evidence of a distinct cretaceous fauna which the Cephalopoda have already established.

The *Pteropoda* appear first in the Silurian epoch (Carboniferous period of Table),

and then vanish to reappear in the Lias. They have not been hitherto found from that epoch upwards till the Tertiary period.

Gasteropoda. Of this great class the well-known recent genus Turritella appears first in the Cretaceous period, increasing in number of species through it and the Tertiary up to the existing. D'Orbigny has described fourteen cretaceous species.

Scaloria: another well-known species, first commencing in this period, to which it has furnished seven species.

Rissoa. D'Orbigny describes one species of this genus, now common in all latitudes, obtained from the gault.

Rissoina,—a sub-genus; one species also from the gault.

Nerinea. This remarkable genus, which commenced in the Oolitic period, yields twenty-six species to the Cretaceous, and then disappears for ever.

Pyramidella. This well-known genus yields its first species to the greensand; the only species of the Cretaceous period.

Actæon (Tornatella of Lamarck): commenced in the Oolites, yielded ten species to the Chalk, and continued through the Tertiaries to the existing epoch.

Globiconcha (D'Orb.): a very globular, nearly spherical shell, with very short and almost concave spire. Peculiar to the upper greensand section of the Cretaceous formation.

Trochus. This genus, so common amongst living shells, was also abundant in the Cretaceous period, to which it yielded thirteen species.

Rotella. This living genus yielded its first species to the Chalk.

Stomatia. A living genus, of hot climates, which produced its only known fossil species in the Cretaceous epoch.

Pterodonta, distinguished from Pterocera by an internal tooth at the mouth, and by the want of a sinus, is peculiar to the upper greensand of the Cretaceous epoch.

The well-known genera *Conus* and *Voluta* existed in the Cretaceous epoch; the former having furnished to it one and the latter six species.

The genera *Mitra* and *Fusus* commence with the Chalk, the latter exhibiting seventeen species.

Colombellina (D'Orb.), confounded with *Rostellaria*, is peculiar to the Cretaceous period.

The common genus *Cerithium* commenced in the Oolitic and became abundant in species in the Chalk, having supplied to its several sections thirty-six species.

Several other well-known genera either appear for the first time in the Chalk or are more fully developed in species than in preceding formations.

The total number of *Gasteropoda* described by D'Orbigny is 325, and he finds the number of species greatly increased in the upper geological divisions, being the inverse of the arrangement observable in the Cephalopoda; so that we may assume, that whilst the peculiar forms of ancient faunæ diminish in number from the base to the summit of the Cretaceous epoch in the class of Cephalopoda, the peculiar forms of our recent fauna in other classes increase,—a state of things natural to a fauna which is on the brink of a still greater change.

M. D'Orbigny draws some highly important geological conclusions from his examination of this great number of Gasteropoda, which will be extracted, as being so well fitted to display the great importance of Palæontology.

1. There are distinct limits to the successive faunæ of the earth, since up to the present time no evidence has been obtained of the passage of any one Oolitic species of Gasteropoda from the Oolitic into the Cretaceous epoch, or of that of a Cretaceous species into the Tertiary.

2. At each great geological epoch there existed not only distinct species, but also genera and zoological forms peculiar to it.

3. No transition being observed in the specific forms from one formation to another, it may be assumed that the succession of organized beings on the surface of the earth was not by gradual passage, but by the extinction of existing races, and the creation of new species at each geological epoch.

4. These conclusions, drawn from the Gasteropoda, confirming in every respect those which have been obtained from the Cephalopoda, it appears that two distinct sets of Molluscs, the one, the Cephalopoda, the inhabitants of deep seas, and the other, the Gasteropoda, the inhabitants of the more shallow water of the sea coast, have combined to testify that the earth has been again and again depopulated, and again renewed in its living creatures.

The great laws which have been thus traced in the progressive distribution of organic bodies, from the consideration of the Cephalopoda and Gasteropoda, are confirmed by the next great class, the *Lamellibranchiata.* These are the headless Molluscs which inhabit bivalve shells. Not possessed of the means of rapid movement like the Cephalopoda, or of crawling on the surface like the Gasteropoda, they are, for the most part, nearly sedentary in their habits, and consequently are the more liable to be limited in their extension, as they are the less able to remove themselves from injurious influences. D'Orbigny has described 553 species in the Cretaceous fauna, but we shall only quote from him a few of the genera which either connect generically the Cretaceous with the Oolitic period, or which, first appearing in the Chalk, are still members of the existing fauna, or which are peculiar to the Chalk.

Opis. This genus, though possessing a general resemblance to the genus Cardium (or Cockle), is very strongly distinguished by its very large and prominent beaks. It is peculiar to the Oolitic and Cretaceous periods, being most abundant in species in the former, though it has supplied to the latter six species.

Crassatella—a living genus in hot climates. The inhabitants of sandy shores, they bury themselves vertically in the sand. They commence with the Cretaceous period.

Cardita, Cyprina, and *Lucina* are considered by D'Orbigny to commence with the Chalk.

Trigonia. This genus, so strongly marked, and so characteristic of the Oolitic period (although one species is assigned by D'Orbigny to an earlier), abounds in the Cretaceous, producing there 21 species; yields only one to the Tertiary, and then in the recent period forms part of the extraordinary fauna of Australia,—a history which suggests to the mind many interesting speculations.

Myoconcha—peculiar to the Oolitic and Cretaceous periods.

Clavagella. This very remarkable recent genus yields its first species to the Chalk.

Leguminaria—a genus which gives very few species to the recent fauna, and gave its only fossil one to the Chalk.

Fistulana—first appears with the Chalk.

Lavignon (*Lutraria* of Lamarck)—begins in the Cretaceous period.

Arcopagia (separated from Tellina)—first occurs in the Chalk.

Thetis—peculiar to the Chalk.

Gervilia—common to the Oolitic and Cretaceous periods, and then ceases to exist.

Inoceramus—abundant in species, and ends in the Chalk.

Janira—a genus now separated from Pecten, &c., containing the formerly so-called P. quinquecostatus, P. quadricostatus, &c., begins in the Cretaceous period, is traceable in the Tertiary, and still exists.

Spondylus — begins in the Chalk.

Ostrea. This well-known genus of our present seas was early represented in the ancient faunæ under peculiar and distinctive forms: to the Chalk it yielded many species, some of which were very remarkable from the complicated manner in which the shell was folded or plaited.

Brachiopoda. —The animals of this great class, which appeared with the very first of organic beings in the most ancient faunæ of the earth, the Silurian, are less perfect in their organization than those of preceding classes. They have no head, have neither organs of vision nor of hearing, and are deprived of all organs of motion. Whether free or attached, the species cannot change their place, and must therefore be peculiarly sensitive of great cosmical changes. It is thus that they have become powerful means of distinguishing formations or epochs, as may be judged from the following statement of the range of the several genera, in which it will appear that they are even more strikingly limited than in the other classes.

Lingula, from the Silurian up to the recent epoch, where it still exists.

Productus — *Chonetes* — *Leptagonia* — *Leptæna*—from the Silurian to the Triasic inclusive, and then disappear.

Orthis—*Orthisina*—*Strephomena*—*Hemithiris*—*Strigocephalus*—*Porambonites*—*Rhynchonella*, — of these only Rhynchonella is continued to the Chalk, where it ceases.

The eight genera constituting the families *Uncitidæ* and *Spiriferidæ*--not continued to the Chalk.

Magas is peculiar to the Chalk, and *Terebratulina* commences with it.

Of the family of *Terebratulidæ*, as restricted by D'Orbigny, the genus *Terebratula* is common to all geological formations, and is still living, whilst *Terebratella*, *Terebrirostra*, and *Fissirostra* are peculiar to the Chalk.

And of the second division of Brachiopoda, *Megathiris* and *Thecidea* appear in the Chalk, and are still living, the latter being attached to Coral at great depths.

Of the family of *Caprinidæ*, the remarkable genera *Hippurites*, *Caprina*, *Caprinula*, and *Caprinella* are all peculiar to the Chalk, and would, even taken alone, stamp an air of peculiarity on the fauna of the Chalk.

In like manner, the curious genera *Radiolides*, *Biradiolides*, *Caprotina*, and *Requienia*, which constituted the family of *Radiolidæ* of D'Orbigny, distinguished the Cretaceous fauna, in which, at several successive stages, their several species were grouped together,—forming in deep water extensive reefs, like the coral-reefs of our present seas. Is it possible, then, to look at such phenomena without at once perceiving that the work of the Creator has been complete in each successive fauna; and that if in one a peculiar object was attained by the instrumentality of certain organisms, that object was equally attained in another, either by the agency of different organic beings, or by a different combination of the same?

These great truths would be equally supported, were we to extend the inquiry to the *Echinodermata*, and specially to the *Echinidæ*, as in the numerous genera and species of the Cretaceous epoch would be found some approximating to our recent types, but many (see Geology Plate XIII.) peculiar to the Chalk. Here also the *Crinoidæ*, which, like the cephalopodous Molluscs of the tetrabranchiate order, commenced with the earliest epochs, and have now almost disappeared or have become comparatively a mere shadow; whilst the Echinidæ have assumed an importance as to numbers which they still maintain. The fauna of the Chalk, therefore, by turns approaches to or recedes from the ancient faunæ, on the one hand, and the existing fauna on the other; but though even a slight specific connection with the recent has

been lately supposed to exist, it presents a bold aspect of difference, which, like a precipice, divides it from our own epoch.

Tertiary Period—(s, t, u, v, w, x of Tables), or excluding x, and merging the local distinctions into the great leading divisions,—the Eocene, Miocene, and Pliocene of British writers; the Quaternary or Pleistocene embracing the still more recent deposits.

Before discussing the flora and fauna of this period, it will be well to refer to Table III., and to consider the proportion of fossil to recent genera in the successive formations, as the evidence of distinct creations or systems is stronger when thus obtained from the greater groups of organized beings than from simple species. The genera may reasonably be expected to be less affected by the comparative areas examined than the species; or, in other words, it is more difficult to account for the total absence of many living genera from the fossil faunæ, and of the similar absence of many fossil genera from the recent fauna, on the mere supposition that it is due to the comparatively small fossil area examined. That reason is legitimate, and has great force, when it is applied to the question of comparative abundance of species, but it cannot account for the want of identity either of species or genera: and if the fact of a want of such identity is remarkable when derived from the smaller groups or species, how much more striking must it be, if found equally deducible from the greater groups or genera! Looking first to the flora, it appears that in the strata deposited during the whole series of secondary formation, from the earliest Silurian to the Cretaceous inclusive, no recent or now living genus of plants has as yet been discovered; whereas in the Tertiary one-third of the genera are still living.

The proportions of living genera in the successive faunæ are as follows:

	Carboniferous.	Trias.	Oolitic.	Cretaceous.	Tertiary.
In the *Phytozoa*,	$\frac{1}{4}$	$\frac{1}{2}$	$+\frac{1}{2}$	$\frac{3}{5}$	$\frac{3}{4}$
„ *Malacozoa*,	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{9}{10}$
„ *Entomozoa*,	$+\frac{1}{10}$	$\frac{1}{10}$	$\frac{1}{2}$	$+\frac{3}{5}$	$\frac{3}{4}$
„ *Fishes*,	0	0	$\frac{1}{10}$	$\frac{1}{4}$	$+\frac{1}{2}$
„ *Reptiles*,	0	0	$+\frac{1}{10}$	$\frac{2}{10}$	$\frac{3}{4}$
„ *Birds*,	0	0	0	0	$\frac{9}{10}$
„ *Mammals*,	0	0	0	0	$\frac{1}{2}$

An examination of these numbers at once points out the enormous zoological difference between the latest of the Secondary formations and the first of the Tertiary,—between, as it were, those epochs of more ancient creations and that in which the world was almost prepared for the reception of Man and the organic beings associated with him.

Leaving out of the estimate Mammals and Birds, the absence of which may be partly due to other causes, how is it possible to explain the change in the numerical proportion of recent genera of Reptiles in the Chalk to that in the Tertiaries from less than $\frac{1}{4}$ to $\frac{3}{4}$,—of Fishes from $\frac{1}{4}$ to $\frac{1}{2}$,—of Entomozoa from $\frac{3}{5}$ to $\frac{3}{4}$,—and in Malacozoa from $\frac{3}{4}$ to $\frac{9}{10}$, without perceiving that a new epoch has opened before us, and that we are gradually approaching to our own age?

The most striking fact which should first be noticed in the Eocene or earlier division of the Tertiaries is the occurrence of Quadrumana in its fauna. These remarkable animals, the next in order of organization to Man, were first recorded as inhabitants of the earth during the Tertiary epoch by Lieutenants Baker and Durand of the Indian army, in 1836, and again in 1837, by Capt. Cautley and Dr. Falconer; but in these cases the fossil remains were from a region the present climate of which

is suitable to the existence of such animals. In 1837, M. Lartet discovered in the fresh-water Tertiaries of the South of France quadrumanous remains, and in like manner they have been discovered in the Tertiaries of South America. In 1839, relics of Quadrumana were found at Kyson, in Suffolk, in Eocene strata; so that their appearance has thus been carried back to the very dawn of our present fauna, and into a country now so unfavourable to their existence. Professor Owen has, however, pointed out, in reference to this latter circumstance, that whilst "the fossil Semnopithecus of India, and Protopithecus, or Capuchin Monkey of Brazil, are, like the lower organized extinct mammals associated with them, of gigantic size as compared with the nearest existing analogues of the same localities, it is interesting to find that the representatives of the quadrumanous order in latitudes the climate of which is now unfit for the existence of apes and monkeys in a state of nature, were of smaller size than their now nearest analogues; a fact which seems to indicate that although the climate was warmer than at present, it was not of so strictly tropical a character as to favour the full development of the quadrumanous type." Whilst, therefore, the Macacus eocænus of Suffolk indicates that such animals could once live in our latitude, it also marks out a commencement of that gradual depression of temperature which at length brought the climate of the later Tertiaries nearly to the level of the present. With the remains of this fossil Macacque were found the vertebræ of the great extinct British Boa constrictor (Palæophis), and the remains of an extinct genus of Pachydermata (Hyracotherium), forming altogether a most remarkable group from this ancient fauna of England.

In the Eocene gypsum of Montmartre, Cuvier discovered the remains of Bats, and their existence in the Eocene sands has been rendered very probable. Such remains are also found in the Bone Caves, associated with extinct animals. In the most recent, (or rather post-tertiary) beds of the Tertiary epoch, remains of the Mole, the Shrew, &c. have been found,—every step bringing us nearer and nearer to the ordinary condition of the existing fauna.

The necessary limits of this article can only allow me to take a rapid sketch of the other peculiarities of the Tertiary fauna. The Chæropotamus of the Eocene strata is a link between the Hippopotamus and the Hog: it resembled the Peccari of Mexico, but was about one-third larger. The genus Hippopotamus occurs in the Pliocene fauna (H. major or great fossil Hippopotamus), and is represented in the Tertiaries of India by its congener, Hexaprotodon of Cautley and Falconer. Of other Pachydermata, the genera Hyracotherium, Palæotherium, Anoplotherium, &c. occur in the earlier Tertiaries, and mark them with a peculiarity which diminishes in the more recent, until at length both the genera and species are nearly identical with those of the living fauna. Of the above animals it has been justly remarked by Owen as a curious fact, that the nearest living analogues of the Chæropotamus, the Anoplotherium and Palæotherium, namely, the Peccari or Mexican Hog, the Llama, and the Tapir, should all be found in South America; so that the grouping of the British fauna in the Eocene epoch corresponded with that of the living South American fauna,—a fact which will remind the student of a similar grouping of the Oolitic fauna as compared with that of Australia. These glimpses of the forthcoming fauna of a prospective creation in such remote epochs are suggestive of much reflection, and are full of interest.

Turning to the Reptiles,—the Eocene epoch was rich in Chelonians, the London clay of our own island having yielded no less than eleven species of the marine genus Chelone, or Turtle. How striking is this fact, when it is recollected that only five well-defined species of Chelone have as yet been discovered, notwithstanding the eager search for these animals, by naturalists and commercial voyagers, in the tropical

seas of our world! Fresh-water Tortoises are still represented in the European fauna by the Emys or Cistudo Europæa, which can live in our own island in suitable localities; but this extraordinary abundance of marine Chelonians in the Eocene fauna of England, — the Island of Sheppey alone producing more species of Turtles than are now known to exist in the whole world, — can only be explained by some great cosmical change. They agree with other organic bodies of the period in demonstrating a warmer climate to have prevailed during that period, and the production, under its influence, of an abundant supply of food. But, in addition to this, Professor Owen advances the truly philosophical opinion, that to some of the extinct species, which, like Chelone longiceps and C. planimentum, have a form of head well adapted for penetrating the soil, was assigned the task of checking the undue increase of the now extinct Crocodiles and Gavials of the same epoch, by devouring their eggs or young; just as in like manner they may have been in return an occasional prey to the older individuals of the same carnivorous Saurians. In the fluviatile Chelonians the same remarkable distinction of the Eocene fauna is preserved.

Of the genus Trionyx, or of the soft Tortoises generally, no species have yet been observed in European rivers, "all those which have been described, and of which the habitat is known, having come from the streams, rivers, or great fresh-water lakes of the warmer regions of the globe;" but at the Eocene epoch the Trionyces abounded in the fresh waters of our latitudes, Professor Owen having described eight species.

Of Marsh Tortoises the numbers were not so great, comparatively speaking, since in the existing fauna this family exhibits the greatest number of species. Two species of the genus Platemys and six of the genus Emys have, however, been described by Bell and Owen; and if the total number of Chelonians disinterred from the Eocene strata of so limited a locality be considered, we shall be almost equally justified in designating it an age of Chelonians as we were in calling the Lias an age of Saurians.

Turning from the contemplation of this section of a fauna which at once embraced so great a variety of Chelonians, Serpents of very large size, great Lizards, and mighty Crocodiles, attention may next be directed to the class Cephalopoda in the Mollusca; but, before quitting the Reptiles, it is desirable to dwell for a moment on the reflections which they have excited in the mind of Professor Owen:

"The fossil reptiles," he observes, "like the fossil fishes, approximate nearest to existing species in the Tertiary deposits, and differ from them most widely in strata whose antiquity is highest.

"Not a single species of fossil reptile now lives on the present surface of the globe.

"The characters of modern genera cannot be applied to any species of fossil reptile in strata lower than the Tertiary formations.

"No reptile, with vertebræ articulated like those of existing species, has been discovered below the Chalk.

"Some doubt may be entertained as to whether the Icthyosaurus communis did not leave its remains in both Oolitic and Cretaceous formations; but with this exception, no single species of fossil reptile has yet been found that is common to *any two great geological formations*.

"The evidence acquired by the researches which I have detailed permits of no other conclusion, than that the different species of reptiles were suddenly introduced upon the earth's surface, although it demonstrates a certain systematic regularity in the order of their appearance. Upon the whole, they make a progressive approach to the organization of the existing species, yet not by an uninterrupted succession of approximating steps. Neither is the progression *one of ascent;* for the reptiles have not begun by the perennibranchiate type of organization, by which, at the present

day, they most closely *approach fishes;* nor have they terminated at the opposite extreme, viz. at the Dinosaurian order, where we know that the reptilian structure made the nearest *approach to mammals.* Thus, though a general progression may be discerned, the interruptions and faults, to use a geological phrase, negative the notion that the progression has been the result of self-developing energies adequate to a transmutation of specific characters; but, on the contrary, support the conclusion, that the modifications of osteological structure which characterize the extinct reptiles were originally impressed upon them at their creation, and have been neither derived from improvement of a lower, nor lost by a progressive development into a higher."

Cephalopodous Molluscs.—In the faunæ of preceding epochs the Cephalopoda have occupied a very prominent position, and have aided materially in characterizing them by the marked and highly important alterations of their structure which became apparent in successive epochs. The family of Nautilidæ exhibited a great variety of modifications at the earliest fossiliferous epoch, namely, the Silurian; whilst the family of Ammonidæ preserved its primæval plan of structure nearly to the Cretaceous epoch, when it assumed all those remarkable forms which have been described under the genera Turrilites, Helicoceras, Toxoceras, Hamites, Scaphites, Baculites, &c., &c.; so that the age of great development of the one family was at the earliest period of the Protozoic formations, and that of the development of the other family at the latest period of the Deuterozoic,—a fact which is strongly in opposition to the theory of progressive development. How remarkable, also, it appears, that after each of these epochs of extraordinary development of forms, the family which was the subject of it should have either relapsed into simplicity or entirely disappeared! most of the abnormal forms of the Nautilidæ, such as the Phragmoceras, Lituitus, Gomphoceras, &c., having vanished with the strata in which they first appeared, just as the similar abnormal forms of Ammonidæ vanished with the Cretaceous, or in the epoch of their birth. The sudden disappearance of the whole family of the Ammonidæ, after so striking an exhibition of creative power in the modifications of its forms, is one of the most remarkable facts of natural history, more especially as it is contrasted with the continued existence of the Nautilidæ, in its simple or normal form, both in the Tertiary and still existing epochs.

But before noticing the Eocene species, let us for a moment turn to the dibranchiate Cephalopoda, and mark the state of their development at this epoch. In the genera Belosepia, Beloptera, and Belemnosis are found connecting links between the Belemnites, which were such interesting members of the Oolitic and Cretaceous faunæ, and the Sepidæ, or Cuttle-fish, of the recent; and these three genera yielded six species to the British fauna. In these forms, therefore, the peculiarities of the more ancient dibranchiate Cephalopoda are disappearing, whilst the characters of the recent are becoming more distinct; but in this, as in the case of reptiles, the change cannot be said to be from the simple to the compound, but rather from the compound to the simple. In like manner, the most simple forms of the tetrabranchiate Cephalopoda have alone been preserved to our recent fauna. The genus Nautilus of Eastern Seas, first made known early in the last century by Rumphius, and first described with accuracy by Professor Owen, was indigenous to our British Seas in the Eocene epoch, having then contributed six species to the fauna of England. These deserve some special notice, in order to satisfy the mind that their claim to a distinction from the recent species is well founded.

Nautilus centralis is small, those found not having exceeded 3″·7 in diameter; and in the simplicity of the septa and the central position of the siphuncle they nearly resemble the recent Nautili, whilst they are distinguished from them by a very ventricose

and almost globose aspect, the dimensions of the largest specimen being 3″·7 in diameter and 3″·3 across. It is probable that this species extends into the Miocene strata.

Nautilus regalis — a very splendid species, as it has been known to attain the size of 9½ inches in diameter and 5 inches across. The umbilicus is closed by a thickening of the lip, which looks like a solid axis to the shell: the siphuncle is small and eccentric; the septa are nearly simple, presenting on each side slight undulations. In the young shell the septum is characterized by a conical depression placed on the dorsal margin, close to the preceding whorl, and having the appearance of a second siphuncle, for which it has been mistaken.

Nautilus urbanus — a flat discoidal shell, with obscure undulations like those of N. regalis. The siphuncle is eccentric, approaching the dorsal margin; the umbilicus is narrow, but open. It is distinguished from N. centralis by its flatness and the greater length of its aperture, and from N. regalis by its open umbilicus and discoidal shape. It attains a large size, namely, 7″·4 in diameter and 3″·4 across.

Nautilus imperialis. — This species is easily distinguished from N. centralis by an eccentric position of the siphuncle, and from N. regalis and N. urbanus by its orbicular form, lunate septa, and recurved dorsal lobes, which form, as it were, an axis to the shell; a very large species having attained the size of 12 inches by 8¾ across.

Nautilus Sowerbyi — a discoidal, or rather a lenticular shell, the aperture having a triangular aspect. The septa are very concave, having on each side a broad undulation with a deep sinus-like depression, caused by a lateral lobe: the siphuncle is very near to the dorsal margin. It has attained the size of 10 inches diameter by 4″·2 across.

Nautilus Parkinsoni.—The septa are moderately concave, with angular lobes on each side. In this latter respect it resembles Aturia zic-zac, whilst it possesses the siphuncle of the genus Nautilus, which, though very eccentric in this species, is still truly discal. It is a connecting link between the Nautili and Clymenidæ, and through the latter leads to the Goniatites and Ammonites. It attains a very large size; the largest chamber in Parkinson's specimen, and that chamber manifestly not the last, measuring 9 inches by 7.

From these descriptions it is manifest that the genus Nautilus was still in a highly developed state in the Eocene formation: it continued so in the Miocene, and it still exists, though now diminished in size and number of species, and confined to the seas of the tropics. It is therefore a connecting link between the extinct and the recent faunæ.

Of the family of *Clymenidæ*, of which the genus Clymenia (Munster) is the type, there is also a representative in the Tertiary, though none in the recent epoch. In the description of D'Orbigny's classification, it was stated that Clymenia, or Aganides (D'Orbigny having adopted the name given by De Montfort to a species which is now supposed to be a Goniatite), having flourished as a characteristic genus in the Protozoic formations, suddenly disappeared, to reappear, as it were, for a moment in the Tertiary. Bronn, however, has established a separate genus for the Tertiary shells, under the name of Aturia, as the whorls are exposed and the siphuncle is narrow in Clymenia, whereas in Aturia the last whorl conceals the others, and the siphuncle in the typical species, Aturia zic-zac, is of great size and funnel-shaped, though in both there is the same position, namely, dorsal and marginal, of siphuncle. These differences, following the analogies of classification in the genera Nautilus and Ammonites, scarcely justify generic separation, unless indeed they had been manifested in a number of species of the new genus Aturia.

The *Aturia zic-zac* (Nautilus zic-zac of Sowerby) was very widely distributed, having occurred in the Eocene strata of Europe and America, and been continued into

the Miocene. The zic-zac or pointed character of the lateral lobes of the septa and the trumpet-shaped siphuncle at present distinguish it as a species.

It has appeared desirable to follow this highly organized class of molluscous animals from its earliest appearance on the earth to the present day, as it affords so many distinguishing characters to successive faunæ, and proves by the high development it attained in the very cradle of its birth, the Protozoic epoch, that no work of creative power was merely tentative, but that every work was matured and perfect. There can be now no doubt, for the conjoint study of Geology and Palæontology leads to such conclusion, that at successive epochs the earth's crust was disturbed, and as it were renewed, and that such changes were accompanied by the destruction of old and the production of new organic creations; but at the same time it may be concluded with equal certainty, that each successive creation of organic beings was formed in relation to the condition of the earth at the time, and that with all the varieties we observe, there is not one assemblage of organisms which can be called imperfect, either as to individual construction or to its adaptation to the office it was created to fulfil. In fact, the varying conditions of the earth required corresponding differences in the organic bodies which were destined to inhabit it, but all and each were framed in harmony with creative excellence. "Thou hidest thy face, they are troubled; thou takest away their breath, they die, and return to their dust. Thou sendest forth thy spirit, they *are created; and thou renewest the face of the earth*."—*Psalm* CIV. 29, 30.

It is unnecessary to pursue this investigation into the other classes of Mollusca which exhibit the continued approximation in genera and species to the recent fauna of the earth, as we have now arrived at that point where the ancient is blended into the modern world. In pursuing our course through this interesting chain of evidences of creative power, we have selected our principal examples from European data, as they were best calculated to exhibit to us the peculiarities of successive faunæ in contrast with that now existing; but had our object been to refer to extinct animals as a necessary portion of the studies of a Zoologist, many very curious examples might have been cited from South Africa and the East Indies.

Even still later in the World's history, the mighty Mastodon and the extinct Elephant, Bear, Rhinoceros, Hippopotamus, Giant Deer, &c., still marked a distinction in the fauna; but as species of most familiar kind were associated with them, such as the Fox, Wolf, Badger, Otter, &c., it is difficult not to consider them portions of the present system; nor indeed is there so great a difference between some of them and existing species as there is between the now extinct Dodo and Solitaire of the Mauritius and Isle of Bourbon, and more common genera and species of those and other localities. In these later deposits, however, may still be noticed the remarkable occurrence of forms now only known in warmer latitudes; and it would appear therefore that they had gradually died out of the Northern faunæ, and been replaced by closely allied species in the Southern. The mode in which these great changes have been effected must ever continue to us a mystery, but the fact has, it is trusted, been made so clear that no unprejudiced mind can reject it.

Distribution of Species.—The distribution of marine animals, which form so large a proportion of those which have preserved to us a knowledge of the more ancient faunæ of the earth, must necessarily deserve attentive study; and for this purpose we cannot do better than examine the principles established by Professor Forbes as the result of his dredging inquiries. He states that the distribution of marine animals is determined by three great primary influences, namely,—climate, composition of the sea bottom, and depth,—corresponding in character with those which determine the

distribution of land animals, namely,—climate, mineral structure, and elevation,—these primary influences being modified by several secondary or local causes.

In the Eastern Mediterranean, eight well-marked regions of depth were each characterized by its peculiar fauna, and wherever plants were present, by its flora. These regions are distinguished from each other by the *associations* of the species they severally include; which assemblages include some species which are only found in that particular zone, some which existed in preceding but do not continue into subsequent zones, and some which, beginning in that zone, continue to exist in succeeding zones.

In this manner certain species have their maximum of development in each zone, and being there most prolific in individuals, may be regarded as especially characteristic. The sea bottom, in its mineral character, has generally a certain uniformity in each zone, that uniformity being more decided in the lower than in the upper zones. The deeper zones are greatest in extent, so that whilst the first or most superficial is but 12 feet, the eighth or lowest is above 700 feet in perpendicular range; and hence the more purely littoral animals were more subject to limitation than those of deep waters.

First Region, or Littoral Zone.—This is the least extensive, as two fathoms may be considered its inferior limit, and its mineral nature is as various as the coast line; but limited as it is, there are well-marked subdivisions. The variety of its bottom necessarily produces, according as it is sand, rock, or mud, a variation in the association of its several species. That portion which, forming the water-mark, is left exposed to the air during the ebb of the tide, presents necessarily species peculiar to itself; species, in fact, which can resist the effect of so great a change, by either closing their valves or burying themselves in the mud or sand. In the lower portion of this zone are the most characteristic species of a locality, and the colours both of shells and animals are most fully and beautifully developed. As local influences, such as variation of sea bottom, differences in tides and currents, flowing-in of rivers, &c., now induce a peculiar or local distribution of species, the same effects must have been produced from similar causes in the ancient faunæ, and the occurrence therefore of abrupt and frequent changes, both in the mineral and zoological characters of a formation, will naturally lead to the detection of a littoral condition of the deposit. The fauna of this belt will be also varied by many stray species, either driven in by storms or brought down by rivers, land shells and plants being frequently mixed up with its true marine inhabitants.

Professor Forbes enumerates from the Ægean Sea 38 species of the Lamellibranchiata and 107 of the Gasteropoda.

Second Region.—It extends from 2 to 10 fathoms, and the sea bottom is generally either sand or mud. In the Mediterranean, the Holothuriæ abound in this region, as do the burying Conchiferæ.

In the Ægean this zone produced 34 species of Lamellibranchiata, and of the Gasteropoda 76 species, so that the number of species is considerably less than in the preceding zone; and it may also be observed that not being entirely beyond the action of the storm wave, its inhabitants are often washed up and carried into the littoral zone.

Third Region—From 10 to 20 fathoms, the sea bottom being generally gravelly in places, with great tracts of sand. This zone presents few peculiarities, and is, as it were, one of transition. Large Holothuriæ are still abundant,—of Lamellibranchiata there are 51 species in the Ægean, and of Gasteropoda 74. There is little doubt that the extension of the muddy sea bottom of the last zone into this, brings also with it an approximation in the zoological characters of the two zones.

Fourth Region—From 20 to 35 fathoms. The sea bottom is very various, mud and gravel prevailing, sandy tracts being very rare. Sponges abound, some of the finest used in commerce growing here. Amongst Fuci, Codium bursa is quoted in this zone; it begins, however, in the preceding in the channel of Corfu.

Of Lamellibranchiate species the Ægean yielded 67, of Gasteropoda 88; in respect to which some cautionary remarks are necessary. Dentalium rubescens, which occurs in the fourth zone, appears also in the first, but not in the second or third: such a distribution seems to imply a mere local result, as the depth of the fourth zone is such as to remove its species from any action but that of currents, and these must have passed the species over the intermediate zones, had they been thus disturbed and moved. Aporrhais pes-pelecani occurs highly developed in the third and fourth zones, but not in the second; but I have no doubt that in other localities it would be found in the second also. In this region the Brachiopoda first appear, yielding two species.

Fifth Region—From 35 to 55 fathoms, presenting a well-marked fauna. The sea bottom is generally nullipore and shelly, mud being rare. Of Lamellibranchiata, in the Ægean, it produces 58 species,—of Gasteropoda 79, and of Brachiopoda 4.

Sixth Region—From 55 to 79 fathoms, nullipore being the prevailing sea bottom. Fuci have become very scarce. Of lamellibranchiate Mollusca 48 species, and of Gasteropoda 43 species, were observed in the Ægean, and of Brachiopoda 5. Pectunculus pilorus is given at its full development, and it occurred also in the fifth zone; but there can be little doubt that it exists also in much higher zones.

Seventh Region—From 80 to 105 fathoms,—has a characteristic fauna, with a sea bottom generally of nullipore, and more rarely of sand or mud. Herbaceous Fuci have disappeared, as also Mollusca tunicata. Echynocyamus amongst the Echinida occurs frequently alive, but its range extends much higher, as it is not unfrequently found alive in the third region in the channel of Corfu.

The Lamellibranchiata yielded only 33 species, and the Gasteropoda 42; but the Brachiopoda were here increased to 7 species.

Eighth Region—includes all the space below 103 fathoms, and extends to the depth of 230 fathoms, having an uniform and well-characterized fauna, distinguished from all the preceding by species peculiar to itself. Within this region the number of species and of individuals diminishes as the depth increases, pointing to a zero in the distribution of animal life not yet arrived at.

The Lamellibranchiata amounted to 30 species, the Gasteropoda to 23, and the Brachiopoda to 3. Of these, only 8 of the Lamellibranchiata were taken alive, and 3 of the Gasteropoda,—all the Brachiopoda and 10 Pteropoda, &c., in addition, being dead. Of the Gasteropoda, 17 species, with 23 Lamellibranchiata and 3 of Brachiopoda, occurred at depths between 140 and 180 fathoms; 4 Gasteropoda, 11 Lamellibranchiata, and 1 Brachiopode, between 180 and 200 fathoms; and only 1 Gasteropode, 4 Lamellibranchiata, and 1 Brachiopode, above 200 fathoms.

The zero of animal life is supposed by Professor Forbes to be about 300 fathoms, the sea bottom being mud without organic remains.

It is found on examining the species with reference to their occurrence in other countries, that those which appear to have existed in a greater number of zones yield a higher per-centage of Celtic or British forms than those which are confined to a smaller number of zones; for example, of those which are common to four or more zones, ⅓rd are Northern, whilst of those which range through less than four regions, only a little above ⅕th are common to the British seas. And from these facts this general law is deduced,—*That the extent of the range of a species in depth is correspondent with its geographical distribution.*

Professor Forbes gives the following Table to illustrate another important consideration in respect to the distribution of species; namely, its variation as regards the different families of Testacea.

Distribution of British Forms in the several Zones of the Ægean Sea.

FAMILIES.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Multivalves	1	0	..	1	1	1	1	0
Patelliform univalves	0	1	2	2	2	2	2	0
Tubular univalves	1	1	0	0	0	0	0	0
Holostomatous spiral univalves	12	9	13	16	14	11	8	4
Siphonostomatous spiral univalves	4	5	7	8	9	6	5	2
Testaceous Pteropoda and Nucleobranchiata	..	..	..	..	..	..	0	0
Brachiopoda	..	..	..	0	0	0	0	0
Conchifera and Lamellibranchiata	16	25	28	39	33	19	11	7
Total	34	41	50	66	59	39	27	13
Per-centage	23	32	40	41	42	33	31	20

From this Table it appears that the least per-centage of the whole number of Testacea is found in the highest and lowest zones,—the greatest in the 3rd, 4th, 5th, and a medium per-centage in the 2nd, 6th, and 7th.

The cause of these results may be traced to the small expansion or range of some species, as may be observed on comparing the number of British forms in the preceding Table with the total numbers in the following.

Distribution of Ægean Shells in Depth.

FAMILIES.	Total.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Multivalves	7	3	2	0	2	2	1	1	0
Patelliform univalves	20	11	3	2	3	5	6	6	1
Tubular univalves	6	4	4	2	2	1	1	2	2
Holostomatous spiral univalves	115	50	40	40	44	35	28	17	15
Siphonostomatous do. do.	104	40	27	30	41	36	30	16	5
Testaceous Pteropoda and Nucleobranchiata	12	1	0	0	0	0	0	3	12
Brachiopoda	8	0	0	0	2	4	5	7	3
Conchifera and Lamellibranchiata	135	38	53	52	68	58	48	34	28
	407	147	129	126	162	141	119	86	66

And it is evident, therefore, that the Geologist, in his reasonings on the fossil faunæ of past epochs, must take into consideration not only the total number of species, but also the number of species in each family, in order to arrive at safe conclusions as to climatal changes; and in doing so he must also bear in mind the great influence of the sea bottom in determining the presence of certain families of Testacea.

It will be readily believed that these zones of depth must be the scene of incessant change, as in one place the mineral matter is washed away, and in another it is deposited, increasing or decreasing the depth; and, in like manner, the same effects may be produced by the depression or elevation of the sea bottom from movements of disturbance, movements which are still continuing, and which were so powerfully exhibited in ancient epochs. In this manner the lateral distribution of a species is often arrested by a change of the sea bottom, and its total annihilation produced by

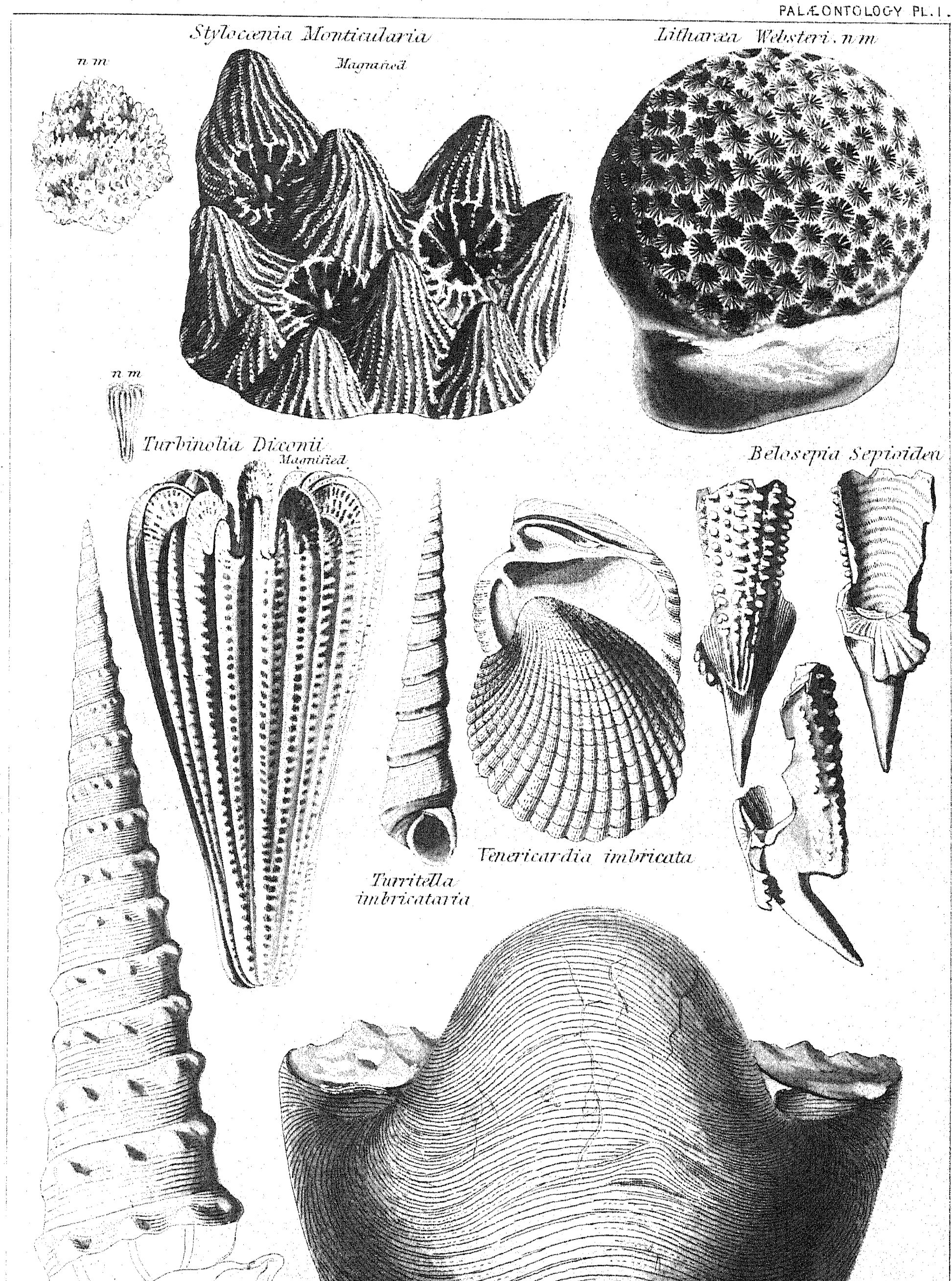
a sudden alteration of the depth suited to its existence. When the change is only in depth, those species which have the power of existing through a great range will be, as it were, singled out of the mass, and continue to live, whilst others will dwindle away and die; but when the change of depth is accompanied by a change of sea bottom, the effect will be at once a diminution in the number of species, and also a cessation of some of the families. Professor Forbes has also justly remarked that the long-continued and undisturbed existence of Testacea, on any ground, must, by the accumulation of their dead débris, render that ground unfit for the continuation of life until it has been covered with a new layer of sedimentary matter, uncharged with organic contents,—so that in this way beds rich in organic remains may alternate with others containing none; a phenomenon well known to the Geologist. Every species has, according to Professor Forbes, three maxima of development,—in depth, in geographic space, in time. In depth, it is at first represented by few individuals, which become more and more numerous, until it has attained that precise zone where all circumstances most favour its growth, when it begins to diminish in number, and at length disappears. So, also, in geographical range, it multiplies until it has attained the climate most suitable to its growth; and in time, or geological range, a similar maximum may be observed; but in this case it should be premised that the duration of a species ought generally to fall within a geological formation.

In applying, therefore, these results of an inquiry into the fauna of the sea bottom to the investigation of more ancient faunæ, the Geologist must bear in mind that there may have been then, as now, a beginning and minimum of development of particular species in some one section of a formation, an increase in its development, as it proceeded from the centre of creation, until it had attained its maximum, and then a gradual diminution to a second minimum. The final limitation or destruction, by whatever cause it may have been produced, of the fauna of a formation, was not therefore always coincident with the duration of a species, but often took place when it was at its maximum of development, as is strikingly exhibited in the fauna of the Chalk, and has been pointed out in the remarks upon the various genera formed after the type of Ammonites, and which, having attained a very high degree of development, were abruptly cut short, and ended with that formation. The study of the sea bottom, as manifested by the nature of the mineral deposits, and the classification of the genera and species according to the probable depth of their usual habitat, must necessarily precede any deductions as to the climate and position of the deposit. Nor must it be forgotten that the limits of the several zones of existence may in the faunæ of former epochs have been greatly modified by climate. There is, however, one feature of extinct faunæ which deserves special notice, as being illustrated by the faunæ of deep zones,—namely, the abundance of Brachiopoda. Were, indeed, the evidence afforded by the genus Terebratula of our recent fauna considered conclusive, the greater proportion of geological formations must have been produced in deep water; but here it may be wise to exercise some caution, and to consider that whenever a class undergoes so great a development in families and genera, some of its forms have been intended to take the place of the species of other classes, and thus have naturally a greater range.

It is thus that Palæontology, viewed as a branch of Zoology, has not only brought before the Geologist proofs of the existence of numerous forms of organic beings, which were associated together in groups not yet fitted for the reception of Man, and which have passed away with the creations of which they were a part,—but has also enabled him to reason with certainty, by reference to the natural characters and habits of extinct animals and plants, on the varying mineral conditions of each successive stage in the Earth's History. He is perhaps surprised at first to find how

EOCENE FOSSILS.

PALÆONTOLOGY PL. I.

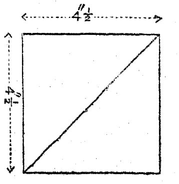


large a share organic beings have had, by their débris, in the formation of those stratified deposits which seem to the uninstructed only crude masses of mineral matter; but when he has discovered order and design in their structure and distribution, he traces in them the power and wisdom of the Creator, as manifested at successive epochs in peopling the world with beings suited to its actual state in each,—and, finally, he is taught that just at that moment when the Earth had been prepared for the reception of Man, a new creation was called into existence, in which every part was so nearly balanced that it was in the power of an intellectual being to hold the scales safely and securely,—Palæontology would have thus enabled the Geologist to discover from the abrupt disappearance of whole families of organic beings, even if he had not been aided by stratigraphical disturbances, the epochs of great cosmical revolutions, just as in the peculiar distribution of ancient animals it has given him a clue to the discovery of every feature of each successive phase of the earth: guided therefore by Palæontology, his eye is carried over the sea shore, the deep sea bottom, the coral reef, the estuaries of the oceans of ancient worlds, of which he becomes at once the Natural Historian and the Geographer.

PALISADES form one of the auxiliary means of defence in Permanent and Field Fortification: in the former they are usually planted in the covert-way, and in the latter in the ditch of a work. The palisade is a necessary security of the covert-way, and the covert-way an important part of permanent fortification, if the ditches are dry, to prevent surprises, and facilitate and support sorties. To fortresses, citadels, and large forts with wet ditches, it is questionable if the covert-way is necessary, and dispensing with the palisade is a great saving of expense, as wood is a perishable article, except to the *couvre-portes*, or works covering the entrances and bridges.

In respect to the palisading of the covert-way of permanent works with dry ditches, several writers, among whom is Carnot, propose to omit the covert-way in their construction, and to substitute the glacis *en contre-pente* (see page 44 of the second volume of this work), arising from the objections to the palisade, on account of the great cost, and its being liable to be destroyed by the enfilade batteries during a siege; but this part of the objection applies only to the fronts attacked, perhaps not more than $\frac{1}{6}$th or $\frac{1}{7}$th of the whole enceinte. Carnot's intention was to discourage passive resistance, and afford the garrison of a place the means of turning the defensive into offensive war, which in very large fortresses is of great importance. However, where there is a covert-way, palisading becomes indispensable, and the palisade is usually fixed on the banquette, about one foot from the glacis, and standing about one foot above the crest. The palisade may consist of young trees, cleft in two, with the flat side spiked into a riband placed at the height of the covert-way, so that the soldier can rest his musket upon it; or it may be of young trees: in either case, the lower end is planted firmly 3 or 4 feet in the ground, and the upper end connected by the riband of scantling or split timbers. When the timber runs large, it is better to construct the palisading of framework, sawn into lengths of about 8 feet and 8 inches square: these will serve for posts. Smaller scantling of $4\frac{1}{2}$ inches square, and 10 feet long, sawn diagonally, as explained in fig. 1, form the rails and palisades. (See figs. 2 and 3.) The palisading is formed into bays about 10 feet from centre to centre, with the two rails tenoned into the post.

Fig. 1.

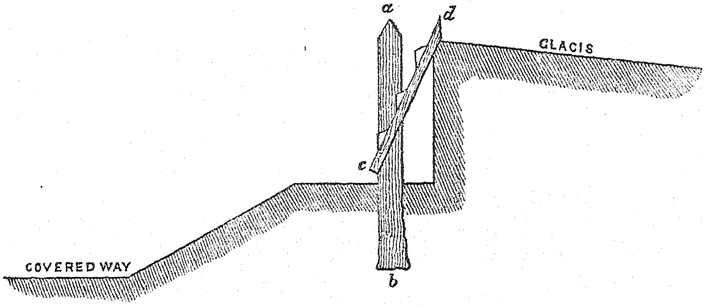


Oak and fir are best suited for palisading.

It has been proposed (see the 9th volume of Professional Papers) to frame the

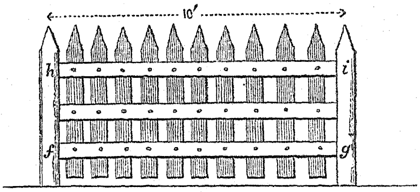
palisading in such a manner as will facilitate sorties, in a better manner than barrier gates, and protect better the troops returning into the covert-way. This may be done by placing one or more bays on a pivot or gudgeon fixed to the posts, and secured at top by a bolt, the gudgeon being on the bottom rail and the bolt upon the

Fig. 2.



upper one. The section of this construction is shewn in fig. 2, *a b* being the post, and *c d* the palisade, sloping back against the crest of the glacis; the ribands, of which an additional one is placed in the centre, serving as steps to mount upon the glacis. This contrivance is less expensive than the ordinary way of providing for sorties, and it does not diminish the security of the covert-way. The diagram (fig. 3) is the same in elevation, but the gate or barrier is closed, *f g* being the gudgeons, and *h i* the bolts for securing the gate when shut.

Fig. 3.



Palisading for field-works is seldom of timber sawn into scantling, but is constructed of unhewn timber of trees suited to the purpose, planted firmly in the ground, and connected above with a riband, into which the palisades are spiked.

The position of the palisading for the security of field fortification should be under musketry fire from the parapet, or from some flanking work, to command the ditch, ~~within~~ a caponière or gallery in the counterscarp; but these are seldom adapted to works of the moment. The position shewn in figs. 53 and 54, Plates VII. and VIII. of Field Fortification, are best for palisading of such works, so as to be seen from the crest of the parapet, and yet be partially secured from an enemy's artillery. The palisading should not be of less dimensions than 6 inches in diameter, and from 10 to 12 feet long, of which 4 should be fixed firmly in the ground.

Sir John Jones, in his 'Journals of Sieges,' note 25, observes—"The French planted admirable palisades in the ditches and rear of their works; each palisade was the rough stem of a young tree or the half of a larger one, fixed to a heavy beam four or five feet under ground. To cut through these palisades, in their usual confined situation, is the work of half an hour, and to force them impossible, so firmly are they planted; they are therefore an excellent defence when covered from cannon."

In the article 'Petard,' it will be seen that even this description of palisade is not secure unless protected by musketry fire.—G. G. L.

PARAPET, according to Bousmard, is from the Italian *parapetto*, or breast-work. The parapet should be shot-proof, to cover the body within from musketry or cannon: against oblique fire, as in flêches or in the zigzag of approaches, the parapets may be less. In the construction of works, local circumstances should be attended to in the height and thickness of parapets, to economize labour, which in field-works is a great object. Hence the normal dimensions given in books, and taught at schools, should be modified accordingly. The height of the parapet above the banquette is another point of great importance in particular cases, as to whether the musket has to be levelled at an object above, horizontally, or at an object below the crest of the parapet; for the soldier must have sufficient command above the parapet, if his piece is much depressed; so that, in fact, the height may vary from 4′ 2″ to 4′ 6″ above the banquette.

Parapets are usually placed in drawings parallel with the exterior faces: practically this is not necessary, as the exterior may be regulated by the ground, whilst the interior line of parapet is guided by the line of approach, or of the probable attack. But a considerable deviation or difference in the two lines would be inconvenient, and generally impracticable.

These observations are merely given by way of reminder, without entering into the elementary construction of works.—G. G. L.

PASSAGE OF RIVERS.

PART I.—MILITARY OPERATIONS AND CONSTRUCTION OF TEMPORARY BRIDGES.*

1. This portion of the subject is intended as a sequel to the articles on Field Bridges given in the first volume: it has been obtained in fragments from various contributors, and is now embodied for the purpose of affording all the information attainable on so valuable a part of the duty of Military Men.

2. The passage of a river by troops or carriages, even when they are not in the presence of an enemy, is often difficult, and generally causes much delay in the march; therefore, as the success of a campaign, and security against disaster, often depend upon the rapidity with which a river can be crossed by an army, all the details connected with this operation should be well considered before it is attempted, so as to prevent unforeseen delay, and facilitate the calculation of the time required.

3. If the river to be crossed lie in the country occupied by an enemy, the best maps and correct information should be procured, and a careful examination made of that part which is likely to be the scene of operations,—noting the source and its mouth,—whether it flows to a sea, lake, or a large river,—the points where it ceases to be fordable and becomes navigable,—where it is joined by tributaries,—the nature of those tributaries,—the places where the river changes its direction,—the towns, villages, and houses on its banks;—also the nature of the bed of the river; its extent during the flood and during droughts, with the cause of the variations; whether there are means of inundating the country, and whether there are any dikes, dams, or canals, and the effect if these are destroyed; the nature of the mouth of the river, if there is a bar, and whether fordable and shifting. In the event of any immediate operation being contemplated, the effect of the tides and winds should be considered; if there are any islands and sand-banks, whether they obstruct or would facilitate a

* By Captain Gibb, Royal Engineers.

passage; and if the sand-banks are liable to shift;—the heights of the banks of rivers should be noted and sketched, if favourable for a passage, and information obtained as to the means of collecting boats or materials for the construction of a bridge or of rafts.

4. *The passage of a river in the presence of an enemy* presents many difficulties: the point where it is proposed to effect it must therefore, if possible, be concealed from the enemy. In the determination of this point, the object of the campaign must be considered,—the advantages which, after the passage, the opposite bank gives for the construction of a temporary bridge, and the security which the ground will afford, by the aid of batteries or other field-works. The banks of the river should not be marshy, and they should be accessible for carriages.

5. In the selection of a point for the passage of a river by an army, the re-entering angle or bend may in some instances be found to afford many advantages, as the opposite bank is more easily defended, the current of the river is less rapid, and there is a greater depth of water for a bridge; and any island in the river gives facilities in crossing as well as in protecting the passage.

6. If the enemy is in force ready to defend the passage of an unfordable river, the operation becomes difficult, as the troops are liable to be cut off in detail as they cross. Most successful operations are secured by stratagem, that is, by deceiving the enemy as to the precise point intended to be crossed: this may be effected by commencing operations at a point which may be changed when it is dark, and crossing at another point which the enemy has left unopposed.

7. As regards the tactical part of this subject, the first operation is usually undertaken by detached means, supported by artillery, when troops are placed in row-boats, or on rafts, collected in the neighbourhood, and passed to the opposite side of the river as hastily as possible, where they secure themselves, taking advantage of localities to keep their ground until supported. When in sufficient strength, the troops should intrench themselves, and be reinforced by artillery. Fords* are sometimes available in the immediate vicinity of a point selected for the passage of an army, which may serve for cavalry and light artillery; but some caution is necessary in the presence of an enemy, as he may cross by the same means, and attack you in front and rear, whilst your force is separated by the river. The passage by swimming† will serve to assist in such operations, where the current is not rapid or the banks abrupt: the direction of the crossing should be with the stream, taking advantage of cross currents and eddies, and keeping clear of rocks. The infantry may convey their arms and ammunition on rafts, or on inflated skins, or pitchers securely connected; or they may take with them a rope supported by cork floats, or any other material inflated. The cavalry should take care, in swimming their horses across, to allow them perfect freedom of motion, the soldier keeping his legs back, holding steadily by the mane, and directing the horse with a light hand. If boats or rafts are used, the horses can swim astern, with their halters attached to them, in all cases taking care that they have plenty of room to avoid touching each other.

8. Before closing these slight preliminary theoretical notices on the passing of troops over rivers, the subject may be considered as strategetic or as a tactical operation. In the first case, the means adopted for passing a river must be of a substantial nature, and a certain degree of permanency must be secured, to stand the effects of the weather, and the probable floods of rivers which generally follow the wet season; and the security of the bridge or ferry against the enterprises of an

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* See article 'Ford.' † See 'Swimming.'

enemy is also an essential consideration. Should the passage form one of the main roads for the supply of the army, or the line of retreat in case of any retrograde movements, great care must be taken to secure it from any possible disaster.* In the second case, considered as a mere tactical operation, the passage of a river will probably be for temporary purposes for the moment or for a few days, when the means required may be slight, and the celerity of the operation of the first importance, the defence of the passage becoming unnecessary. All well-organized armies are furnished with a bridge equipment to each corps, at least, with one for the advanced guard; but whether the passage is formed of materials obtained on the spot, or by a bridge equipment, they are usually removed after the passage is effected. Up to this date (1850) it does not appear that the means of passing rivers have been brought to perfection, nor are bridge equipments of a sufficiently portable nature to accompany corps and detachments in rapid movements in difficult countries. Field Bridges are still cumbersome, and a large establishment of men and horses is required to transport the equipment. In the British Service, in fact, there is no fixed establishment for effecting the passage of rivers.

9. *Rules for ascertaining the Width of a River; 1st, without Instruments.*

To ascertain the inaccessible distance A X (see fig. 1), measure any convenient length A C or A C′ in the prolongation of A X; and if the ground will admit of a line being laid down perpendicularly to the right or left of A, measure the triangles A B C or A B′ C′, making the sides in the following proportions; viz. A B = 4, A C = 3, and C B = 5, and prolong A B to any point D; then lay down D O in the same way perpendicularly to A D, and fix a mark at a point in it which is in the prolongation of B X.

Fig. 1.

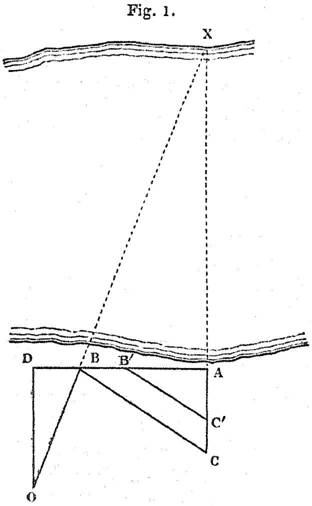
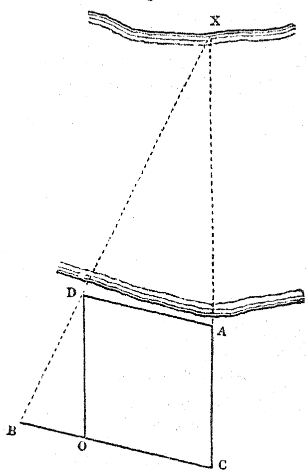


Fig. 2.



Then, as B D : B A : : D O : A X.

Or (see fig. 2) measure A D in any convenient direction, and make O C equal to it, also measuring D O equal to A C, and then fix a mark at B in the prolongation of D X and O C.

Then, as B O : D A : : D O : A X.

* See 'Tête du Pont.'

2ndly, with a Sextant, Compass, or Theodolite.

The lines may be laid down as in fig. 1, taking care to make the angle B A X = B D O, and the calculations may be made as before; or measuring A B as a base, and ascertaining the angles X A B and X B A, the distance A X may be found by trigonometry.

10. *To find the weight which any floating body will support*, first calculate the number of cubic feet of water displaced by it, which for solid timber and air-tight cases may be considered equal to the entire bulk; but for open boats, which cannot be safely immersed lower than within 9 inches of their upper surfaces, the bulk below that level can only be calculated on. Multiply the number of cubic feet of water displaced by 1000 for fresh water, and by 1026 for salt water, which will give the weight in ounces: from this must be deducted the weight of the body itself with the superstructure, and the difference will give the weight which can be supported. The weight in ounces of the materials is found by calculating their cubic feet, and multiplying that by their specific gravity, which for oak is 950, for elm 670, and for male fir 580; but it must be remembered, that if timber be not tarred, its weight will be increased $\frac{1}{8}$th by imbibing water after being immersed two or three days. The weight pressing upon a bridge during the passage of infantry four deep would be that of 20 men, or about 3600 lbs., on a length of $12\frac{1}{2}$ feet. Two cavalry horses abreast, with their riders leading them, would occupy 12 feet, and the total weight would be about 2640 lbs. A medium 12-pr. brass gun and its limber occupies 14 feet without the horses, and its weight is about 5000 lbs. including the limber and ammunition. A brass 9-pr. or 24-pr. brass howitzer weighs about 4200 lbs., and a light 6-pr. or 12-pr. howitzer about 3000 lbs. (For the weights of Ordnance and Carriages, see the first volume.)

In crossing temporary bridges, cavalry should always dismount, and infantry should never be allowed to keep step: cattle should be driven over in very small numbers at a time.

TEMPORARY BRIDGES.

11. The following resources for facilitating the passage of troops across rivers are added to the article 'Bridge, Field.'

Large trees may be felled to enable infantry to cross a narrow stream, placing them so that their butts may rest upon the banks with the tops directed obliquely up the stream: if one is not long enough, others may be floated down so as to extend across, being guided and secured by ropes: a footway may be formed by laying planks or fascines or hurdles over them, and their branches should be chopped off nearly to the level of the water, and interlaced below; poles also may be driven into the bed of the river, to aid in supporting the trees by attaching the boughs to them.

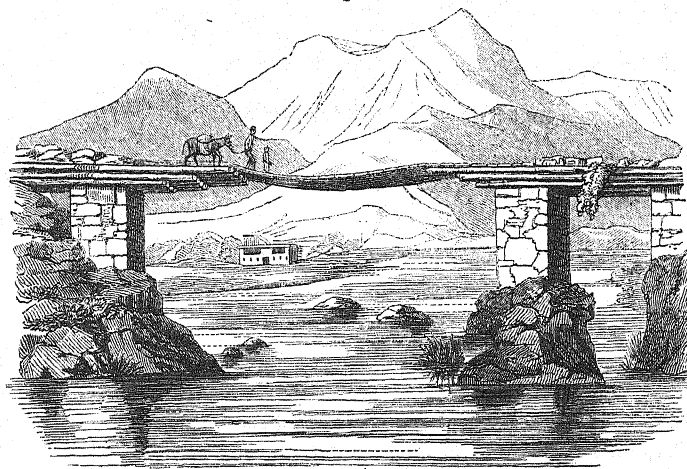
12. *Wheel carriages* may be used to form a foot-bridge, if the river is not too deep, being pushed or hauled into the stream, and connected by beams; or a single pair of wheels, with an axle-tree to ~~admit~~ two strong posts may be attached, ~~and~~ placed in the centre of the stream, if not too wide, and poles reaching from each bank may be secured to the posts, and the wheels would act as a trestle: with a flooring over the poles, a slight bridge could rapidly be constructed.

13. *A Wicker Bridge.**—"The bridge across the Zab at Ligan is of basket-work; stakes are firmly fastened together with twigs, forming a long hurdle, reaching from

* From 'Nineveh and its Remains,' by A. H. Layard, Esq.

one side of the river to the other. The two ends are laid upon beams resting upon piers on the opposite banks. Both the beams and the basket-work are kept in their places by heavy stones heaped upon them.* Animals, as well as men, are able to cross over this frail structure, which swings to and fro, and seems ready to give way at every step. These bridges are of frequent occurrence in the Tigari Mountains."

Fig. 3.



Wicker Bridge across the Zab near Lizan.

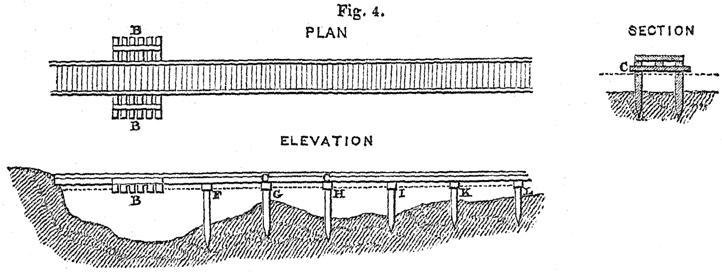
14. *Hide-boats*, &c. have been used in India and elsewhere. For military operations on the rivers of the American prairies, they are made of four buffalo hides, strongly sewed together with buffalo sinew, and stretched over a basket-work frame of willow, 8 feet long and 5 feet broad, with a rounded bow, the seams being then covered with ashes and tallow: after being exposed to the sun for some hours, the skins contract, and tighten the whole work. Such a boat, with four men in it, only draws 4 inches of water.

15. *Inflated skins* have been used since the earliest times for crossing rivers; and if four or more are secured together by a frame, they form a very buoyant raft. *Canvas*, rendered water-proof, and stretched over a frame-work or wicker-work, will serve also ~~as~~ for a raft or pontoon. The detachment of Royal Sappers and Miners at Sandhurst made some wicker-work or gabion pontoons in the following manner: Light poles were fixed upright in the ground in a circle, and brush-wood weaved upon them exactly as is done in making gabions, a scaffold being of course required for the workmen to stand upon when the weaving was too high for them to work from the ground; and the conical ends were added afterwards, made of the same materials. When the canvas was stretched over this wicker-work, it was payed over with a composition of pitch 8 ℔s., bees'-wax 1 ℔., tallow 1 ℔., boiled together, and laid on quite hot; the cracks which appeared on its hardening being closed by means of a hot iron.

16. *Pile Bridge.*—"On the 16th July, 1809, two companies of the Staff Corps were directed to make a bridge across the Tietar River, near Placentia in Spain, where the profile of the river was found as explained in the following diagram.

* For a military operation, probably a rope extended across the river on each side of the hurdles would be better.—*Ed.*

Fig. 4.



The dotted lines shew the water level.

"The only materials at hand were the timber of a large house, about half a mile from the place. This building was unroofed, and the following was found available:

6 beams of dry fir, 2 feet square and 20 feet long;
400 rafters, 6 by 4 inches, and 10 feet long;
6 large doors; and
200 running feet of mangers.

"Of the six large beams the raft B was made by boring holes through the centre of each, towards the ends, and passing ropes through them: this raft was placed in the deepest part of the stream, and the broad ends turned towards the current; one end of the rope was made fast to a tree on the bank, and the other to a stake. A working party of 500 men, with saws and axes, was sent to a distance of three miles to procure young pine-trees to cut the piles and caps, as shewn at C in elevation and section of diagram; and the horses,* ten in number of two piles each, were fixed as explained at C; the bearers E, F, G, H, I, K, L, made of the baulks, were laid on the caps of the horses, cut into scantling of 6 inches square. The flooring of the bridge was made of the doors, mangers, and rafters, which were found sufficient." †

17. *Temporary Bridges of Gun and Mortar Platforms.*—As the power of crossing streams which separate the various corps investing a fortress, or placed in position to resist an attacking army, is often of vital importance, and may even decide the result of a campaign, Captain Bainbrigge, Royal Engineers, has suggested, that whenever materials for gun or mortar platforms baulks are provided preparatory to the attack or defence of a fortified position, or any fortified place, they should be prepared in such a form as also to admit of their being made use of for the construction of bridges, rafts, &c. To attain this object, he has proposed that they should consist of baulks 10 feet long and 4 by 3½ inches, adapted to the construction of platforms similar to those invented ‡ by the late Colonel Alderson, R.E., which may be rapidly framed into various kinds of bridges adapted to the nature of the streams to be crossed, by substituting for dowel-pins and holes, intended to connect them, iron or oaken pins, from 10 to 20 inches long, and ¾ inch diameter, to receive which each baulk must have five holes, ⅞ths of an inch in diameter, bored through it at equal distances apart, whereby they can be connected and formed into solid platforms; and by screwing nuts into the ends of the iron bolts, these baulks may be converted into bridges, without alteration or injury to their capacity for again forming platforms for

* It has been explained in another part of this work, that among carpenters and sawyers the horse has only two legs and the trestle four.

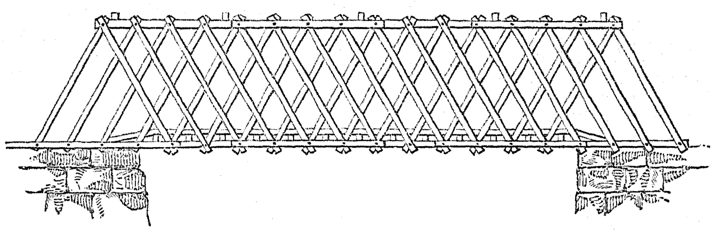
† Notes from Papers of the late General Sir George Murray, Quarter-Master-General.

‡ See article 'Battery,' vol. i.

guns and mortars; and the following different descriptions of bridges which can be made solely of platform materials were tried in 1846, at the Royal Military Repository, Woolwich, and were approved by the Officers of the Select Committee ordered by the Master-General and Board to report upon them:

18. *First, a Trussed Lattice Bridge*, as shewn in the diagram below, fig. 5, having a span of 28 feet, consisting of two separate frames, which were put together on the bank and hauled into their places by ropes,—which might perhaps be facilitated by stretching hawsers across, upon which they might slide: the baulks were lashed across over the tops of these frames when fixed perpendicularly in their places, 8 feet apart, so as to brace them together. Baulks were also placed with their ends resting

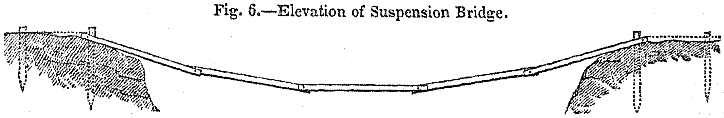
Fig. 5.—Elevation of side of Lattice Bridge.



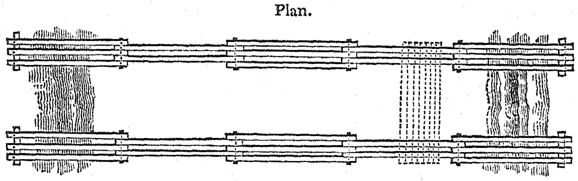
on the lower string-pieces of each frame, to support the flooring for the roadway, which, for want of a sufficient number of baulks, was composed of pontoon chasses: the bolts were only applied along the top and bottom of each frame, as marked in the figure, thus requiring 72 bolts and 102 baulks. An 18-pr. gun with its limber, weighing 65 cwt., was drawn over this bridge without causing any appearance of weakness, and other experiments shewed that a similar bridge, constructed with half the proportion of crossed baulks in the side frames, and with a span of 50 feet, would suffice for the passage of 6-prs.; and that probably, if the lower edges were strengthened with additional baulks or ropes, 12-pr. guns might cross with safety.

19. *Secondly, a Suspension Bridge.*—The baulks of the platform were fixed in strings as follows, spanning 32 feet, laid down 7 feet apart, and parallel: baulks were also

Fig. 6.—Elevation of Suspension Bridge.



Plan.

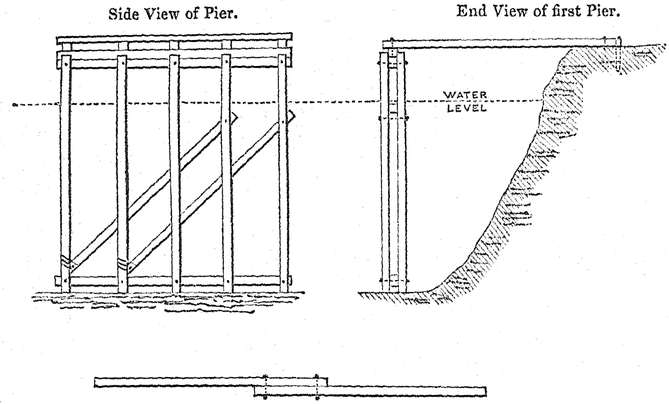


laid across the strings, so as to support the roadway: the ends of each string, having been hauled tight, as explained in fig. 6, by a block tackle, were secured by pickets driven into the ground, against which the bolts connecting them rested; but they might be attached to trees or to rocks, &c., if found more convenient. Each set of baulks was connected with the ends of the next set by a single bolt, therefore

only 12 bolts are required for this bridge; and supposing (as in the lattice bridge) that the flooring baulks were placed 2 feet apart, and the roadway formed of planks or pontoon chasses, only 48 baulks are required for it. A 12-pr. brass gun with its limber, weighing 36 cwt., was taken over it without causing any appearance of weakness, and one string of baulks was also loaded with $37\frac{1}{2}$ cwt. (equivalent to 75 cwt. on the whole bridge) without causing any effect except a slight depression resulting from the pickets, which were not sufficient: these were fixed as shewn in dotted lines in the elevation of the bridge, fig. 6.

20. *Thirdly, a Trestle Bridge,* one pier of which is shewn in fig. 7, is first framed together and placed perpendicularly in its position by launching it out from the

Fig. 7.—Trestle Bridge.

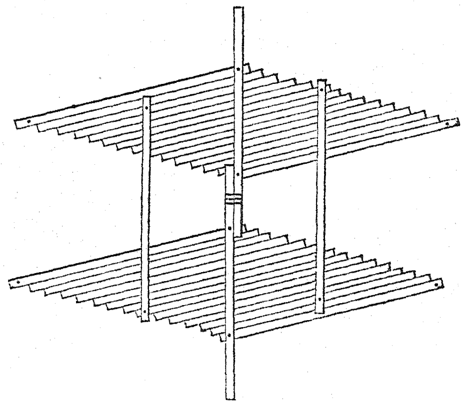


shore over two poles. The trestle, when framed as above, being loaded at the bottom with stones, is boomed out by means of baulks attached to its top by lashings, which secure it in its position, and support the roadway when fixed: similar piers are then placed in succession 9 feet apart, and iron pins may be used to secure the baulks connecting the piers, which also support the flooring. Supposing, as before, that this is composed of planks, 85 baulks and 68 bolts are required for a bridge of this kind, 40 feet long. Such a bridge has a great advantage over ordinary trestle bridges, in presenting a very narrow surface to the current, and thus preventing floating trees or ice from collecting against the piers, and carrying them away; for greater security against which, the sides may also be boarded over. As this bridge appeared capable of supporting any weight required, no guns were taken over to try it, the ground being inconvenient for that purpose. Ice-breakers formed of similar baulks, fixed so as to form a sloping edge, over which the ice would rise and break itself, may be added to each trestle.

21. *Fourthly, Rafts.*—Platform baulks were rapidly framed into a light raft, as explained in fig. 8, consisting of two or three layers of baulks, crossing each other, and joined together by others bolted to them above and below, so as to form a diamond-shaped raft, which was found to be capable of being rapidly paddled about by one man; and by connecting two of these together, as shewn in the following diagram, a more capacious one was constructed, which supported a 6-pr. brass gun; and by adding others on each side, a continuous bridge can be formed, in which case the rafts may be further apart. A single raft, consisting of two

layers of baulks, requires only 33 baulks and 4 bolts, and may be put together in an hour by four men.

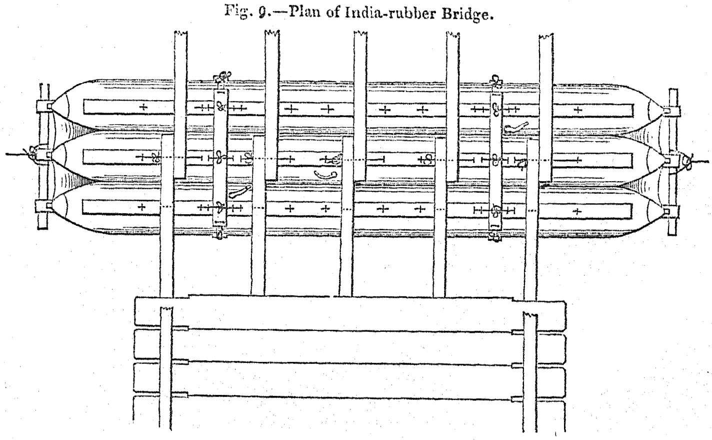
Fig. 8.—Plan of Raft.



These four experiments, tried by Captain Bainbrigge at Woolwich, and explained in paragraphs 18, 19, 20, and 21, shew how timber of very small dimensions can be applied in the Passage of Rivers, and will suggest methods of using materials of very irregular scantling and lengths, which may be put together with pins of hard, tough wood, instead of iron.

22. *Vulcanized India-rubber Pontoons.*—The following account of this description of floating bridge is extracted from the fourth number of the Papers published by the United States' Military Engineers in 1849. These pontoons would prove particularly useful where transport is difficult, as each pontoon, consisting of three cylinders connected together, weighs only 260 lbs., and with a flooring of three chesses is capable of being paddled about for the purpose of casting anchors, &c. (see fig. 9), and can be packed in a box 5 ft. × $3\frac{1}{2}$ ft. × 1 ft.

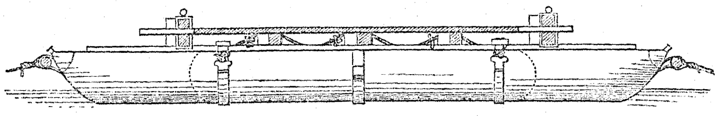
Fig. 9.—Plan of India-rubber Bridge.



23. "The India-rubber pontoons are made of India-rubber cloth, and consist each of three tangent cylinders, peaked at both extremities like the ends of a canoe:

the ends are firmly united together by two strong India-rubber ligaments which extend along their lines of contact, and widen into a connecting web towards the ends, in proportion as these diminish,—the whole thus forming a single boat 20 feet long by 5 feet broad, of great buoyancy and stability, and from its form and lightness presenting but trifling resistance to the water. Each cylinder, including its peaked extremities, is 20 inches in diameter, and is divided into three distinct air-tight compartments (see fig. 10), each of which has its own inflating nozzle. The middle

Fig. 10.—Side View.



The dotted lines shew the compartments.

compartment occupies the whole width of the roadway of the bridge. The pontoon nozzles are made of brass, as shewn in detail in fig. 11, and are in two parts, the stopple and tube, the former screwing into the latter, to open or close the nozzle: the tube consists of two cylinders of different diameters, but having the same axis. The stopple is a hollow cylinder, with four circular openings on the sides, for the ingress and egress of the air, and is closed at the lower base by a flat cap, a little larger than the diameter of the cylinder, so that the projection catches against a small side-screw, to prevent its coming out; though, by first removing the screw, the stopple can be taken out if necessary.

Fig. 11.—Section of Nozzle.

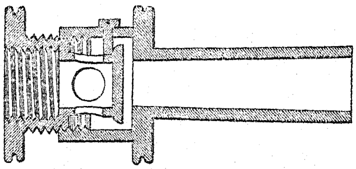
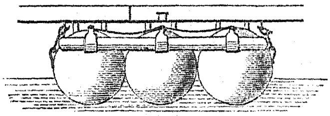


Fig. 12.—End View.



24. "*The Frame and Roadway of an India-rubber Pontoon.*—The frame lies on the top of the pontoon, to which it is lashed (see figs. 9, 10, and 12), and serves as a means of attaching the baulks to the pontoon, and preventing their chafing it: the baulks are of white pine or spruce, 19 feet long, 4½″ wide, and 4½″ deep; the chesses are also of white pine or spruce, 13 feet 9 inches long by 1½ foot and 1½ inch. (See figs. 9, 10, and 12.)

25. "*Manufacture of India-rubber Pontoons.*—The pontoons are made of two thicknesses of strong, heavy cotton duck, coated with metallic rubber, the outer thickness being coated on both sides, and the inner thickness on its outer side only, making three rubber surfaces or layers. In preparing the caoutchouc gum for coating the duck, it is first cut up into small pieces, and carefully washed to rid it of all dirt and impurities, and is then passed between two grinders, iron cylinders revolving with different velocities, and heated by steam to about 150° Fahrenheit, and then mixed with white-lead and sulphur, in the proportion of 25 ℔s. of gum, 10 ℔s. of white-lead, and 3 ℔s. of sulphur. When the rubber becomes plastic, and is well mixed with the sulphur and white-lead, it is laid aside, and, after a few days, is again passed through a second series of revolving cylinders, more nearly in contact, and heated like the first; and after it is made perfectly homogeneous, and about as soft as putty, by this second grinding, it is passed through a third set of revolving

cylinders, longer than the width of the duck to be coated. Upon one of these cylinders a thin sheet of rubber is formed, which is brought nearly in contact with another cylinder, over which the duck is passed from a drum around which it is wound. By the compressing power of these cylinders, the rubber is so forced into the meshes of the duck, and firmly united with its surface, that it cannot afterwards, without difficulty, be removed. In like manner several additional thin sheets of rubber are placed upon the cloth. The coating of the other side of the duck is similarly executed, and, if designed for the outside of the pontoon, a little colouring matter is added to the rubber, to make it dark, the natural colour of the gum being a light yellow. Inflating nozzles, one opening into each compartment, are inserted in the pontoon: the bellows for inflating the pontoon does not differ, except in the formation of the nozzles, from that in ordinary use.

26. "*Repair of India-rubber Pontoons.*—The greatest danger to which these India-rubber pontoons are exposed is that of being perforated by the musket-balls of an enemy opposing the passage of a river. Should a shot-hole be made in a pontoon while forming the bridge, it may be temporarily stopped, without removing the pontoon from its place, by an India-rubber patch, a few of which the pontonier-serjeants should always have in their pockets. The patch is made of two circular pieces of India-rubber cloth, 3 inches in diameter, having a small hole in the centre, through which passes a string of soft cord, knotted at one end, which will completely fill the hole. One of the circular pieces is crowded into the pontoon, and drawn tight against the inside of it by the patch-string, where it is kept in its place by the inner pressure of the air, while the other circular piece is slipped over the string hard against the outside of the pontoon, and secured in place by tying a knot close to the outer surface of the patch. Larger holes could be stopped in a similar manner, but would of course require larger patches. For the repair of small shot-holes, the torn edges should be trimmed, making the opening of the inner thickness of the pontoon, say, about an inch in diameter, while the outer thickness should be removed for a diameter of 3 inches, and all the old gum (which, after being vulcanized, will not adhere to new) carefully scraped off from the outer surface of the inner thickness for the same diameter of 3 inches, and from the outer surface of the outer thickness for a diameter of 6 inches. The hole being thus prepared, three or four coats of India-rubber cement, thinned, if necessary, with a little camphine, are put on the inside surface of the pontoon by the finger or a brush, for a width of about 2 inches around the hole, each coat of cement being dried in the shade before the next is put on. A patch of strong duck, 5 inches in diameter, and coated on one side with cement, is then adjusted on the inside of the pontoon, so that the centre of the patch will correspond to the centre of the hole: a second patch, 3 inches in diameter, and coated with cement on both sides, fills the openings cut out of the outer thickness of the pontoon; and a third patch, 6 inches in diameter, of vulcanized India-rubber cloth, coated on one side and cemented on the other, is put concentrically over all."

27. *Observations on India-rubber Pontoons.* — The equipment and management of these pontoons are nearly similar to the means employed for bridges of a different kind, the floating portion constituting the only essential difference; and this being light and compact when folded up, its transport will be easily effected. Looking at the equipment of the whole in the Service of the United States' Government, it appears too large and unwieldy to accompany an army, except in countries where the roads are good. As regards the floating portion of these pontoons, several diagrams have been given to explain its nature; and it presents so many advantages, that it will probably be adopted in our Service, with some modifications in the equipment. Similar pontoons were used by a party of Royal Sappers and Miners under Serjeant M'Leod,

of that corps, at the Cape of Good Hope, during Lieut.-General Sir Harry Smith's expedition against the Boers in 1848; and by means of two of them, when formed into a raft, horses, artillery, and waggons were ferried over the Orange River when in flood and very rapid.

PART II.—PERMANENT BRIDGES.*

This second portion of the article is extracted from a treatise by Lieut.-Colonel Abbott, C. B., of the Bengal Engineers: in his preface the author says—"This little essay is not intended for the experienced Engineer, its aim being to afford a few simple rules to those who, without the advantages of professional education, are frequently called upon to superintend the construction of bridges in India. I have confined myself at present to the consideration of bridges of masonry as being most generally useful, and I have used the plainest forms of calculation; thus enabling any overseer, tolerably well acquainted with the rudiments of arithmetical computation, to solve the few problems required.

"In calculating the thrust of the arch, I have omitted the effect of weight of the arch itself in steadying the pier, as the introduction of that element would place the question beyond the reach of ordinary mathematicians. The treatise may be useful to local committees in the construction of ordinary bridges; but when large rivers have to be dealt with, the advice of a Professional Engineer should be taken, as there are many points of local consideration which will occur to the practised mind alone."

SECTION I.—EQUILIBRIUM.

Equilibrium of an arch is that condition in which all its component parts balance each other, and are thus enabled to remain at rest without the aid of friction or of cement.

2. In general practice it will be necessary to consider equilibrium merely as it affects the abutments or supports of the arch. This *result* of equilibrium is called 'the thrust' of the arch.

3. It is indeed possible so to construct an arch with roadway, that the fabric shall destroy itself: such was the arch built by William Edwards in his second attempt to span the River Taaf. His arch was a semicircle of 140 feet diameter. The deep haunches, being filled in with solid masonry, proved heavy enough to force up the central portion, when of course the whole building fell. This is an extreme case, and could only occur with semicircular or Gothic arches, and of very large span; and such arches may even be rendered perfectly safe by piercing their haunches with openings, or by using other methods (hereafter shewn) to lighten them.

4. This overloading of the haunches is the greatest danger to which the arch itself is subject, and although it applies with little force to arches of flattish outline, yet modern architects usually reduce the weight upon the haunch, not only with reference to equilibrium, but with a view to decrease the expense of the work.

5. With the above precautions duly observed, and with others of form and thickness, &c., which will be mentioned in their proper places, we may assume as a practical truth, that if an arch be properly supported at its feet, it will stand firmly. This leads us to the subject of Section II., viz. 'the thrust of an arch.'

SECTION II.—THRUST.

Professor Barlow has shewn that the lines of thrust in all arches follow certain

* By Lieut.-Colonel Abbott, C. B., Bengal Engineers.

curves which are of the parabolic class, the exact species of that class being determined by the nature of the loading. The common parabola is however the most generally known, and as its errors are all on the side of safety, it is particularly convenient for our purpose: we may therefore assume this rule.

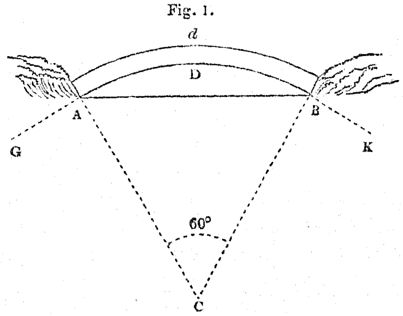
Rule. The thrust at any point of an arch is always in the direction of a tangent to some parabola at that point.

2. It is not necessary to exhibit here the several methods of constructing a parabolic curve, the properties of which are generally understood by Professional Engineers.

3. It is found on comparing the parabola with the circle that the two curves very nearly correspond up to a certain length, and that about 60 degrees of every circle may be *practically* assumed as the upper portion of some parabola; so that by confining ourselves to the use of 60° of a circle we have an arch whose line of thrust may be immediately obtained by drawing a tangent to the circle, or a perpendicular from the radius at its intersection with the circle. See fig. 1, where A D B is an arc of 60°, and the lines A G, B K, perpendicular to the radii C A, C B, respectively, are tangents to the circle, and represent the line of thrust of the arch.*

4. Beyond the extent of 60°, the line of thrust becomes tangent to that parabola of which the arc A D B forms the summit. Without adverting, in this place, to the method of finding the thrust, we will see how the arc of 60° can be turned to account in most practical cases.

Fig. 1.



5. In a segmental arch of 60° the radius is equal to the span,—the rise of the arc, or 'versed sine,' as it is called, is between $\frac{1}{7}$th and $\frac{1}{8}$th of the span,† which, although less than is usual in India, is common in Europe.

6. Draw another curve from the same centre C, but with longer radius, so as to represent the thickness of an arch of masonry; then, if the feet A and B stand upon rock, we have a substantial arch in equilibrium, or of such a nature, that if each of the arch-stones had its sides radiated towards the centre C, and if, instead of mortar, something even greasy or slippery were introduced between the joints, the arch would still remain firm.

7. Having ascertained the direction of the line of thrust of the arch, fig. 1 or 2, *i. e.* the angle that this line makes with the horizon, we can compute with tolerable accuracy the amount of force with which the arch pushes in a horizontal direction against its abutments.

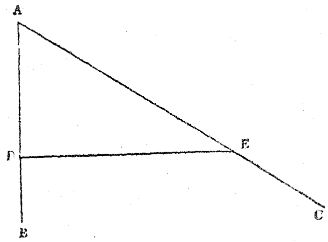
Rule. Find the solid content of the arch from which its weight can be computed; then multiply half this weight by the cotangent of the angle of inclination of the line of thrust. The product will be the horizontal thrust of the arch upon *each* of its abutments.

* To find C, the centre for describing the arc,—take the length A B in the compasses, and with centres A and B describe two arcs cutting each other at C.

† The rise or versed sine is found by multiplying the span into the decimal fraction ·1339746. This applies only to the segment of 60°,—in other cases multiply the radius by which the arc of 60° is described into the same fraction.

8. To work out the question by lines, so as to avoid the use of Mathematical Tables, draw any vertical line A B; from A draw A C, making the angle B A C equal to the difference between 90° and the angle of inclination that the line of thrust makes with the horizon. Set off on A B, from a scale of equal parts, half the weight of the arch in pounds, cwts., or tons, from A to D; draw D E perpendicularly to A B, to cut the line A C at E; then D E, applied to the same scale of equal parts, will shew the horizontal thrust. (See fig. 2.)

Fig. 2.

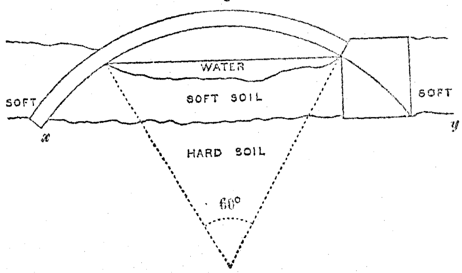


SECTION III.—ABUTMENTS.

In figures 1 and 2 we have arches striding from bank to bank of the river, the natural soil being supposed to be firm enough to bear the weight and thrust of the arches. But as such soil is seldom found in practice, it becomes necessary to build a mass of masonry, called an abutment, at each end of the arch, and these abutments must be founded upon substantial soil.

2. If the line $x\,y$ (fig. 3) represent a stratum of solid soil, clay, rock, or gravel, &c. lying below softer earth, it would appear necessary merely to continue the parabolic curve down to the line $x\,y$, but in such a case an injurious strain would be occasioned by the superincumbent mass of earth; it is therefore necessary to give upright abutments, although at a considerable sacrifice of material.

Fig. 3.



3. The springing line of an arch should be kept as low as possible, compatible with safety and convenience, as by such precaution the mass of the abutment is reduced. The height of the springing line is, however, regulated by circumstances. When there is no traffic upon the river, the springing line may be a few inches above the highest possible floods, remembering that the construction of a bridge will frequently raise the floods above any previously experienced.

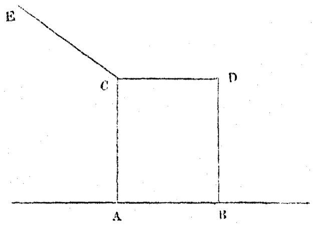
4. Where rivers are used for navigation, the abutments must be sufficiently raised to admit of towing-paths, and the arches must be sufficiently elevated to allow loaded boats to pass freely beneath them.

5. Any unnecessary addition to the height of an arch or an abutment not only wastes material, but causes either an awkward ascent or the necessity of additional approaches.

6. Having fixed according to circumstances the height of the springing line of the arch, as well as the height of the roadway, it becomes necessary to determine the thickness that must be given to the abutment, to enable it to resist the thrust of the arch. This is a very difficult part of the Engineer's art. Judging from the extraordinary diversity observable in works of the most celebrated architects, it would appear that scarcely two of them had been guided by the same rules or principles.

7. An abutment may be considered as a compact mass, A B C D, (fig. 4,) liable to be moved from its position, either by being turned over on its heel B by the thrust along the line E C, or by sliding on its base A B. When the abutment is lofty, it will be more likely to turn on its heel; when low, it will be more likely to slide. Resistance to the first motion is comparatively easy of estimation. Resistance to sliding is a problem involved in much obscurity, for want of a complete knowledge of the laws of friction. We can therefore, in this latter case, work only by approximation.

Fig. 4.

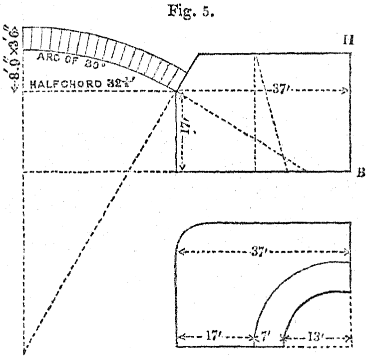


8. The resistance of the abutment against turning on its heel B is (independently of the earth behind it) represented by the mass of the abutment A B C D multiplied into half its thickness, or half A B, but if we suppose the arch and abutments to be composed of the same sort of stone and brick, we may then dispense with solidity, and work by surfaces, which will be more convenient.

9. The proposed method of determining the thickness of an abutment to resist the effort of an arch to turn it over, will be best illustrated by an example.

10. The abutment arch of the Hutcheson Bridge, Glasgow, (fig. 5,) built by Mr. R. Stevenson, is a segment of 60 degrees of a circle, the radius and span being each 65′. The line of thrust, which is tangent to the circle at the springing, forms therefore an angle of 30° with the horizon. The thickness of the arch is everywhere 3′ 6″. The height of the springing line is 17′, but the abutment is carried up solid to a mean height of 26 feet.

Fig. 5.



11. To find the thrust of the arch, it will be requisite to allow for the roadway and occasional loading of the arch, and when the material is stone, 18 inches added to the thickness of the arch will cover all. The arch then is 5′ thick, and the length of the half-arch is 35′, and $5 \times 35 = 175'$ is the area of the half-arch; this, multiplied by the cotangent of 30° or $1{\cdot}732 = 303{\cdot}1$, is the horizontal force acting upon a lever 17 feet long; therefore the total force to be resisted by the pier will be $303{\cdot}1 \times 17 = 5152$.

12. To find the thickness of abutment necessary to resist the above thrust,—let H be the height of the abutment, and B its thickness; then $H \times B$ will represent its area; and supposing this, as in the area of the arch, to represent the weight also, we have to multiply it by half the thickness or half B (by the laws of the lever). Therefore $H \times B \times \frac{1}{2} B$ or $\frac{H \times B^2}{2}$ will represent the vis inertiæ of the abutment. Now to make this just balance the thrust, we have the equation

$$\frac{H \times B^2}{2} = 5152;$$

from which the value of B will be found to be 19·6 or 19′ 7″, which is almost exactly what Mr. Stevenson has given to the solid part of his abutments.

13. The above thickness enables the abutment just to balance the arch and its load, but it is advisable to have a preponderance in favour of the pier: this may be given by the addition of buttresses called 'counterforts.' Mr. Stevenson has made those in the example before us very massive; they are two buttresses 17′ long and 12′ mean thickness, with a horizontal counter-arch between them. I should, however, deem it safe to give four counterforts, each having a length equal to one-third or one-half of the thickness of the abutment, and a breadth equal to one-tenth the breadth of the same.

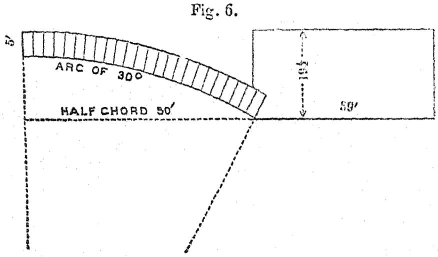
14. The above example was taken from a number of plans of bridges, merely because the arch happened to contain 60° exactly. The Wellesley Bridge at Limerick corroborates this theory very closely; the calculated value of B being 13′ 10″, whilst the thickness of the solid part of the abutment, as executed by Mr. Nimmo, is 15′, and there are also three counterforts, each 6′ long and 4′ broad. But on the other hand the Bridge of Jena, in Paris, being a segment of 54′ with a chord of 91′ 6″, and versed sine of 10′ 9″, and where the value of B is calculated at 28 feet, the architect, M. Lamande, has given the enormous thickness of 45 feet, or half the span of the arch.

15. When the arch is elliptical, the line of thrust will be calculated as a tangent to a parabola from the point where the parabolic curve cuts the abutment produced upwards.

16. With reference to the second mode of failure, viz. by the abutment sliding upon its foundation, Mr. Rennie's experiments with roughly dressed granite seem to shew that the friction with this stone is somewhat greater than half the weight; and taking into consideration the tenacity of the cement, the resistance afforded by the two, may, with safety, be considered as equal to three-fourths of the weight, if not fully equal to the whole. However, limiting the effects to three-fourths of the weight of the abutment, we will suppose the following case:

17. Let A D B be a segmental arch of 60°, A B being 100, D d 5 feet, (fig. 6.) The rise or versed sine will be $13\frac{1}{2}$, and the surface of roadway may be 2 feet above the key-stone, so that the total height of the abutment will be $13\frac{1}{2} + 5 + 1 = 19\frac{1}{2}$ feet. The thrust falling at the foot of the abutment, it is plain that it will be more likely to slide upon its base than to turn over upon its heel. The force or horizontal thrust will be $6\frac{1}{2} \times 50 \times$ cotangent $30° = 576$; and the equation of equilibrium will be

Fig. 6.



$$H \times B \times \tfrac{3}{4} = 576;$$

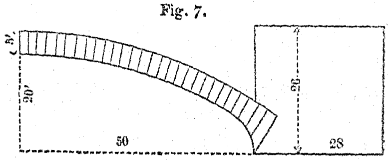
or,

$$B = \frac{576}{H} \times \frac{4}{3};$$

and as $H = 19{\cdot}5$, B will equal 39 feet, nearly. Some little allowance may be made for the sake of safety.

18. In figure 7, where the rise is one-fifth of the span, the value of H is 26, and this reduces the value of B to 28.

Fig. 7.



19. That the thrust of an arch is exceedingly diminished by the tenacity of the masonry, when consolidated, was shewn by an accident which occurred very recently with an old bridge of considerable size. The valley, which is extensive, is crossed partly by the bridge and partly by a viaduct pierced at intervals by small arches.

20. In the rains of 1842, one end of this bridge, 130 feet, consisting of six small arches standing on box-work 9′ deep, was undermined, together with a portion of the causeway. The waterway being considered insufficient, it was proposed to substitute a set of arches, varying from 30 to 21 feet span, in place of the injured portions of the bridge and causeway. The overseer in charge, by some strange oversight, proceeded to dismantle the injured arches, without taking any precaution towards supporting the next sound arch (a semi-ellipse of 30′ span and 7′ versed sine), which was thus left abutting on a pier 6 feet thick and 11 feet high. Such an abutment was much too weak, and under the thrust of a fresh arch would have been overturned, but the old arch merely opened a little underneath the key-stone, and threw the abutment slightly out of the perpendicular. A heavy buttress was then applied, until the new companion arch could be turned (a semi-ellipse of 31 feet span). On the centering of this new arch being struck, the pier resumed its original position, and the crack of the old arch closed up.

21. This example is instructive, inasmuch as it shews that one-fifth of the span is not sufficient for the *abutment* of an elliptic arch of similar span, rise, and supports; and these proportions are very commonly used in regard to piers.

22. It is not recorded that any opening or crack took place between the springing and the crown of the above arch, which, according to some theoretical writers, ought to have been the case: however, it is by no means certain that such an intermediate crack did not take place.

23. I have omitted from the calculations all consideration of the steadiness imparted to the abutment by the *vertical* pressure of the arch; this element would render the subject too abstruse for the ordinary builder; nor do I believe that it has ever been considered *practically*.

SECTION IV.—PIERS.

A pier is an abutment supporting the feet of two instead of only one arch: it then ceases to be an 'abutment,' as the horizontal portions of the thrust of the two arches *abut* against and balance each other, leaving only the vertical or perpendicular portion of the thrust (which is simply the weight) to be borne by the pier.

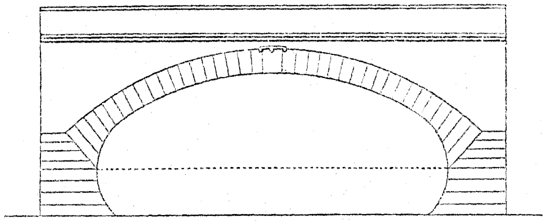
2. Now the weakest material of which a masonry bridge is constructed, viz. brick, is so strong in resisting a crushing force or weight, each square foot being estimated as capable of bearing about 80,000 lbs. weight, or 35 tons, that a pier 2 feet thick would (without other considerations than that of the mere weight) suffice to support the feet of two arches of 200 feet span each, and 2 feet thick or deep.

3. In practice, however, arches meeting on a pier do not always counterbalance each other completely. The pier, if very thin, would be rickety, and liable to be split or bent by the load, although the bricks themselves would not be crushed: it is therefore usual to give a much greater thickness to piers than is absolutely necessary for supporting the load.

4. Some Engineers consider it necessary that a pier should be strong enough to act as an abutment to the other arch, in the event of one arch being broken. But this would generally require the pier to be one-third or one-fourth of the span, and this would interfere too much with the waterway. One-fifth and one-sixth of the span are both practised in India, and they give a light and elegant pier: this thickness is measured at the summit of the pier.

5. It is a good practice to build piers with a slope or 'batter,' thus making the thickness greater at the foot of the pier. This not only imparts steadiness to the pier, but causes it to oppose a greater surface against the soil, rendering it less liable to sink into the soil. This slope or batter need not exceed 1 in 12. With low elliptic arches, it is common to give a considerable batter, but in the form of the

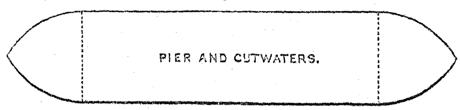
Fig. 8.



curve (*vide* figure 8), which gives a very elegant appearance, it reduces the water-ways, and is only allowable on particular occasions.

6. In running streams of any magnitude it is advantageous to shape the ends of the piers into cut-waters, for the purpose of passing the water through the arch with as little turmoil as possible. The best form for such purpose would be that of a very sharp wedge, but this would be weak in itself and dangerous to boats. A very good form (fig. 9) is obtained by describing arcs from each corner of the pier with a radius equal to the thickness of the pier. In small bridges, or where the current is slack, it will be sufficient to describe semicircles on the ends of the piers as diameters, as in fig. 10.

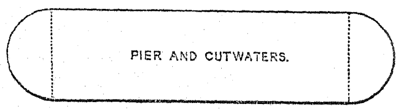
Fig 9.



7. Piers should be built in a very solid manner and with very fine joints, to obviate settlement.

8. The summit or head of a pier should rise above the highest flood level.

Fig. 10.



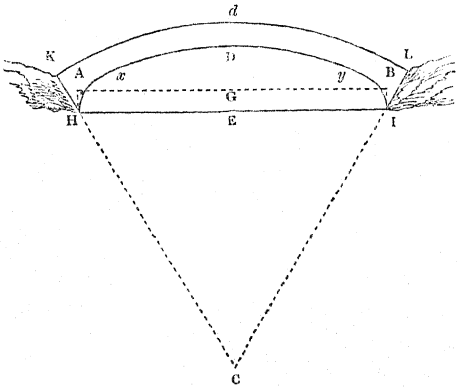
SECTION V.—THE ARCH.

There are only two curves well adapted to bridge purposes, viz. the segment of the circle and of the ellipsis or oval. The first is the simplest, but a constant repetition of it would be tedious to the eye, which requires variety, and this is afforded by the ellipse and its modifications.

2. There are many ways of drawing an oval: we will here see how the segment of 60° may be converted into an oval, so nearly resembling the true ellipse as to be hardly distinguishable from it, even on measurement. (Fig. 11.)

3. Draw the arc ADB as in fig. 1; draw the perpendicular radius CD, and upon it set off DE equal to about one-fifth of the span AB. Through E draw HEI parallel to AB, making AH, BI, equal to half GD. From the points x and y, taken at about one-fourth of the half-arcs AD, BD, draw by the aid of the eye the curves xH, yI, to complete the oval. This is a very graceful curve, and has a very

Fig. 11.



convenient rise: its thrust is exactly the same as in figure 1.

4. To obtain the back or 'extrados,' after having determined the depth of the key-stones D d, take C d as radius, and from the centre C describe the arcs K d L.

5. The voussoirs or joints are all drawn towards the centre C.

6. The form of the arch may be varied by making the versed sine D E greater or smaller in proportion to the span.

7. One of the most graceful arches in Europe is a semi-ellipse, whose rise is less than one-sixth of the span; it is built of marble. The arches of the town bridge on the canal at Kurnaul, built by Colonel J. Colvin, of the Bengal Engineers, are of similar proportions, and are built in brick. Very flat curves require care and attention in setting the joints accurately; but care and attention should be bestowed upon every arch, however simple its form.

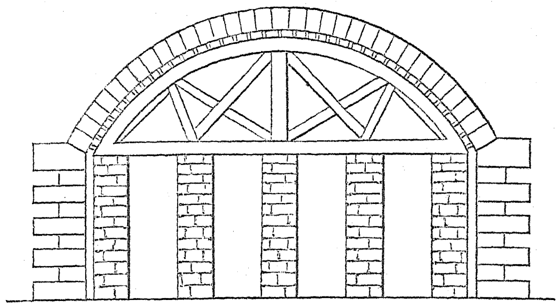
8. Gothic, Mohammedan, and other pointed arches are not well suited for bridges, as they require a more than convenient rise, besides being mechanically objectionable.

9. *Thickness of Arch,* or the depth of the key-stone.—Authorities and examples differ very much in regard to this fundamental. Key-stones, which generally denote the depth of the arch at the crown, have been actually constructed from $\frac{1}{10}$th to $\frac{1}{47}$th of the span. If it were necessary to guard against dead weight or thrust simply, the depth of arch actually necessary would be very small; but as vibration is one of the most dangerous enemies of a bridge, it becomes expedient to give such solidity as to reduce this action within safe limits. In large arches of stone, $\frac{1}{30}$th of the span, or thereabouts, is a favourite depth of key-stone with modern architects; but this would be much too small in small brick arches of 30′ and 40′ span. Brick being lighter than stone, and the compressive force of a small arch being much less than that of a large one, the equilibrium would be more easily disturbed by a passing load. For brick arches of 40 and 50 feet span, $\frac{1}{18}$th of the span will be found a good thickness; for 30′ spans, $\frac{1}{15}$th; for 20′ spans, $\frac{1}{10}$th; and for 10′ spans, $\frac{1}{5}$th: it is false economy to allow less than 20 or 24 inches to the smaller bridges or culverts.

10. *Turning the Arch.*—Preparatory to turning the arch it is necessary to provide a form or 'centering' on which to lay the bricks or stones of the arch itself. In Europe, centerings are made of timber, but in India, where timber is generally scarce, and the spans of bridges usually small, pillars of mud-cemented masonry are built between the piers or abutments, and on these may be laid either a wooden frame coinciding with the form of the intrados of the arch, or a form of brick and mud-work may be substituted. *Vide* figures 12 and 13.

11. Such centres will only be applicable to arches which can be turned with certainty before the periodical floods take place. Where this is not possible, piles must be substituted for the pillars; or centres of timbers must be made, which will stand by resting upon the piers. These latter require considerable mechanical skill and are very expensive.

Fig. 12.

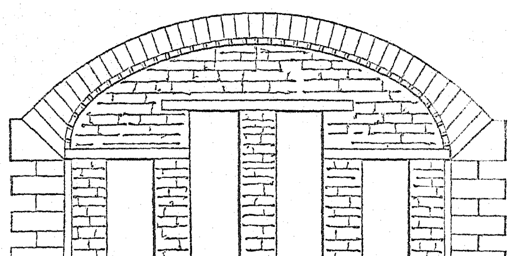


12. Upon the moulded surface of the centre, the arching bricks are laid, commencing at the haunch and taking care to make the two sides approach equally towards the centre, and to leave a space at the centre just sufficient to receive one brick as a key-stone. This brick or key should be inlaid with finely ground mortar and be driven home with a few light taps of a wooden mallet: care must be taken not to use too much force, or the arch will perhaps start near the haunches.

13. *Joints.*—All the joints should be radiated at right angles with the curve of the parabola; but where only 60° of a circle are employed, the bricks are all radiated to the centre of the circle. When the span is 20′ and upwards, it will be needless to dress each brick to the form of the arch; it will suffice to make the joints as small as possible, recollecting that the bricks should be in actual contact, the cement merely filling up their inequalities.

14. When the arch is keyed or completed, the centering may be removed. This operation should be performed by excavating the earthen mould from below the centre of the arch, working thence towards the haunches, and by equal gradations on either side of the centre, otherwise the arch might settle unequally and be strained.

Fig. 13.



15. *Bonding.*—As far as 40 feet, a very simple mode of bonding the masonry of an arch has been found successful. The bricks are all laid on edge with the centering, and are carried round from pier to centre in concentric rings: horizontally they break joint across the arch: arching of this pattern is hardly more expensive than common wall-work, but it is found to be inapplicable to very large spans.

16. The most usual mode is that of the common bond. One brick is laid on edge to the centering, its length laying in the direction of the breadth of the arch; the next brick is placed with its end upon the centering and its length in prolongation

of the radius, thus breaking joint on the thickness as well as on the breadth of the arch.

17. *Cements.*—One of the best cements ordinarily to be obtained in India is made of one part stone lime and two parts fine *soorkee; bujree* or gravel being seldom fine enough for arch joints. The lime should be fresh and caustic; the soorkee should be made of the soundest bricks. The two ingredients should be mixed and ground dry under a *chuckee* or grinding-stone, and should then be slaked with just sufficient water to make them into a paste. If fine bujree be used, the same mode of treatment is to be observed. The quality of the cement depends greatly upon the lime being slaked from its caustic state whilst in contact with the gravel or soorkee.

18. *Haunches.*—To relieve the shoulders or haunches of the arch from unnecessary weight, as well as to save material, thin longitudinal walls, called spandril walls, are built at intervals, extending from the abutments nearly to the centre: their summits support either slab-stones for covering the intervals, or small vaults of masonry.

19. These walls may be $1\frac{1}{2}$ or 2 feet in thickness; their intervals, where flags are used to cover them, must depend upon the size of the stone procurable. When vaulting is used, the intervals may be $3\frac{1}{2}'$ or $3'$; the outer walls in this case should not be under 2 feet.

SECTION VI.—ROADWAY.

On roads of great traffic, and when the bridges are small, they should be the full breadth of the road. But when bridges are large, this would cause them to be too expensive; they should not, however, be less than 24 or 25 feet in clear width of roadway between the parapets.

2. A flat or level roadway is the most convenient, but where a rise is necessary, the slope should not exceed 1 in 35, or 1 foot of rise to 35 feet of base.

3. Above the extrados or back of arch there must be laid a course of bricks on edge, fixed in mortar, and over this a layer of $6''$ of metal (beat down from $9''$): this surface should be well drained by means of outlets through the parapet walls.

4. The roadway should always be guarded by parapet walls, varying from 3 to 5 feet in height and from $1\frac{1}{2}$ to 2 in thickness, according to the nature of the bridge. These walls are continued with a curved splay outwards from the end of the bridge, to form proper entrances or approaches.

SECTION VII.—TREATING OF THE FOUNDATIONS FOR BRIDGES, ESPECIALLY IN INDIAN RIVERS.

Hitherto I have considered the abutments and piers as standing upon solid soils, their bases being spread out to give a better footing; but in India it too frequently happens that this precaution is not sufficient. The general character of the earth's crust, in India, is a superstratum or upper layer of clay, varying in quality by its mixture with sand or vegetable mould, and varying in thickness from 3 feet to 20, or even more, with a substratum of sand to great depths, but generally containing thick or thin layers of clay, or *kunkury* clay, lying at various depths below the surface of the sand.

2. When rivers run in the upper stratum of clay without cutting through it, their streams will generally be found to be sluggish, having little slope, and running across or obliquely with the general line of drainage. With such streams it will be necessary merely to sink the footing of the piers and abutments a few feet below the bed of the stream; but where the clay has been cut through, exposing the sand, it becomes necessary to take further precautions for fixing the feet of the piers and abutments.

3. Sand, when free from the action of running water or other disturbing forces, is by no means a bad foundation; it is superior to many kinds of clay; but in the bed of a river, and under even the most gentle current, it is liable to be moved, and is therefore quite unfit for the footing of piers, &c., and it becomes necessary to seek artificial means of securing the foundations.

4. With small bridges, and where the current is not very strong, and where the natural waterway has not been much diminished by embankments, it is sufficient to support the bridge upon 'boxed foundations.' These are formed by making large boxes of wood of the shape of the pier or abutment, but about 9″ or 12″ larger each way as to length and breadth. The boxes have neither tops nor bottoms, and their sides vary in height from 6 to 10 feet, according to circumstances. These boxes are driven into the sand by scooping from the interior, and they are then filled with rubble masonry. Upon this masonry the piers and abutments are built.

5. Beyond the depth of 10 or 12 feet, it is better to use wells or blocks of masonry.

6. Wells* are familiar to the natives of India, who have used them as foundations for many centuries. The class called Well-sinkers are very expert; almost any Raj Mistree will lay off the walls of a foundation. When a cut-water is used, care must be taken to have it also supported by a well or part of a well.

7. 'Blocks' are a variety of the well foundations. In this case a frame of stout wood, well joined, is made in the shape of the pier or abutment, being a little wider each way. Upon it is raised a mass of masonry, conforming to the shape of the wooden frame or 'Ny-chuck.' The masonry is pierced by wells, varying from 3′ to 5′ in diameter, and placed at various distances; but the largest wells should not be more than 3 feet apart. When the pier or abutment is very large, it may be divided into two or more portions. These masses are driven down after the manner of well-sinking; they are capable of being well loaded, and they may be sent downwards with great nicety, and are not so apt as wells are to topple over. They are more expensive than wells, but are much firmer.

8. Blocks may be laid at distances of 8 and 10 feet, the intervening spaces being covered by arches: this is economical in large works.

9. A Table is given of the rates and times of block-sinking, compiled by Major W. E. Baker, of the Engineers, from the day-books of work at a canal bridge.

10. The following remarks apply equally to wells or blocks.

11. These foundations may be supported in two ways, either by driving them down to the solid soil,—clay or kunkur, or rock,—or they may be suspended, as it were, in the sand, by mere friction, the force of which is very great in sand; so much so, that beyond the depth of 40 feet or so the labour of sinking the masonry becomes excessive, and unless the head be well weighted by extraneous loads, there is great chance that the lower portions will drop away into the hollow formed by the excavators; but by heavily loading the summit, wells have been driven 50 feet through sand.

12. If the river's bed were not disturbed to any great depth by the action of the water, there would be no necessity for sinking the wells very deep; friction alone would suffice to uphold them; but Indian rivers have this peculiarity, that during eight months of the year they occupy very narrow channels, and during the rest of the year they flow with broad and rapid streams, sometimes overflowing the country for miles on either side.

13. It would be too expensive to carry a bridge over the whole or even one-half or

* See 'Corps Papers,' vol. i. p. 50.

one-third of this flood: it is therefore usual to embank the greater portion of the low ground with a stout mould of earth, restricting the river to such a channel as we may have the means of bridging.

14. Such reduction of the waterway causes the water to rise in a heap above the bridge, and this occasions a rush or rapid through the arches, sufficient to tear up the sand to a great depth; so that shallow foundations would be rooted up.

15. The uprooting force of these rapids extends to great depths, as is shewn by the following facts:

16. In 1831 a masonry bridge of three arches, each of 60′ span, was built over the Neem Nuddee, on the road between Futtehgurh and Koel. The river there runs in a wide shallow valley, and for eight months in the year has no stream, being nearly dry: it takes its rise below Boolundsher, about 35 miles above the bridge, and as it is hemmed in between the Ganges and the Kalee Nuddee, it cannot drain a greater area than 150 square miles; yet in the rains of 1838 the floods came down with such violence that they rose above the crowns of the arches, and then excavated the soil below the foundations until the whole mass, excepting the abutments, fell into the gulph.

17. The arches were flat ellipses, springing low, and with splayed piers, described in Section IV. par. 5. The foundations were wells, sunk to the depth of 20 feet, and were supposed to rest on good clay.

18. The eastern Kalee Nuddee takes its rise in a swamp close to Kotowlee, Mozuffernugger district, and about 25 miles north of Meerut. It is like the Neem Nuddee above described as to its valley, and its dry-weather appearance. The slope of the bed does not exceed 14 inches per mile; the river drains an area of about 250 square miles.

19. Over this river and on the Gurhmooktesur road, close to Meerut, a masonry bridge of three arches, each of 25 feet span, was built in 1840; it was supported on wells running down 22½ feet below the river's bed, and supposed to rest upon a strong stratum of clay, mixed with kunkur.

20. In the rains of 1842 a heavy flood occurred; the water rose 8 feet perpendicularly: it did not reach the crowns of the arches, but it rushed with such violence as to scoop out the sand to a depth of 23 feet, or 6 inches below the footing of the wells. The wells dropped perpendicularly 6 inches, and there stood (it is supposed) on the real kunkur-bed: the bridge did not fall, but the arches split into many fissures. On attempting to remove the arches, the whole went down into the pool. Had the pool been filled with sand previously to this attempt, the foundations might have been saved, but would hardly have been trustworthy.

21. Too much caution can hardly be used in ascertaining, by personal inspection, whether the wells have reached a solid stratum. Native workmen, anxious to get this laborious part of the operation over, generally try to persuade the architect that the wells are firmly footed. I think it highly probable that the wells of the Kalee Nuddee bridge had been stopped just 6 inches short of the solid soil, and that 6 inches more of sinking would have saved this useful construction.

22. The piers of a suspension bridge of 400 feet waterway had been completed on the Hindun river near Delhi, and the abutments had been connected with the high bank by an earthen causeway, measuring a mile from end to end, when, in the rains of 1844, the waters rose 11½ feet, and scooped out the sand from the eastern end to the depth of 25½ feet. The pier at which this occurred stands upon wells, as do all the rest; but the wells of this one, after having been driven to the depth of 34 feet, moved with so much difficulty as induced the architect to stop the work, leaving them supported by sand alone. Great apprehension was entertained regarding this

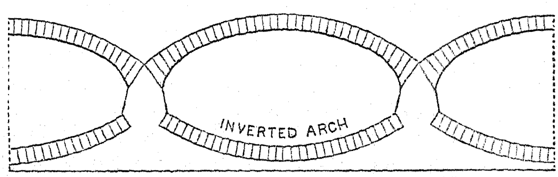
pier, whose wells were actually bare of all but water, to the depth of $25\frac{1}{2}$ feet: they remained firm, supported by the friction upon $8\frac{1}{2}$ running feet of their lower extremities: sand-bags were thrown in, and before the occurrence of another flood the pool was filled up.

23. In Europe, wooden piling is used to a considerable extent in securing foundations, but it is not often applicable in India. As it is necessary to the durability of the piles, that they should be completely covered by water at all times, and in large rivers, where they might be so submerged, the great depth of sand, sometimes 50 feet, is beyond the reach of the largest timbers procurable in the Upper Provinces,—nor could the pile be driven to that depth in some cases,—timber piles might be scarfed, but they would be more expensive than wells, which are nothing more than piles of masonry.

24. Piling, however, is often used as an auxiliary in defending the feet of causeways and the wing walls of bridges, also in protecting the curtain walls where flooring is given below the arches; but all these are on a small scale, and the subject requires little notice. In driving piles, it is better to use a heavy weight with a short drop, than a light weight with a long drop. By the former the work is more speedily executed and the pile-heads are less injured; and when driving piles in sand, especially quicksand, the blows should be given as quickly as possible. The moment the pile ceases to vibrate, the sand settles around it, and lessens the effect of the next blow: the longer the intervals between the blows, the less will be the effect of each. A pile half-driven in sand, and left for any length of time, will be sometimes found immoveable.

25. Instead of using piles or wells or other deep foundations, the piers and abutments of moderately sized arches are supported upon inverted arches, as in fig. 14.

Fig. 14.



These arches, by distributing the pressure over a large area, enable a bad soil sometimes to resist the weight of a bridge, which it could not do if the pressure were concentrated in the narrow areas of the piers and abutments.

26. Such a foundation is only applicable where the soil is not liable to be moved; for it is evident that if the soil were washed out from below the centre, the arch at that part would very probably drop down.

27. Inverted arches will sometimes save a weak clay soil from being cut by a rush of water through the bridge. In this case there should be curtain walls, some few feet deep, drawn across the opening from pier to pier, to prevent the arch from being undermined. A row of piling is sometimes given instead of the curtain wall, but the wall is the best: sometimes both are used, viz. a curtain wall resting upon piles.

28. In large bridges, where water is generally to be found at the very footing of the piers, it would be extremely difficult to turn an inverted arch, and as the soil in such cases is generally sand, the arch would be unstable.

29. In cases where the waterway of a large bridge is found to be dangerously small, the foundations are sometimes secured by a flooring of masonry. This flooring should be 4 or 5 feet thick, and besides lying between the piers, should extend 20 feet

beyond them, both up stream and down; the outer edges being guarded by curtain walls, if possible, or by rows of piles: sheet piling (stout planks of wood would be the best, if procurable at moderate cost). It is better to avoid the necessity for these costly additions by allowing a sufficiency of waterway in the original design.

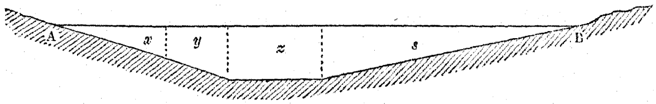
SECTION VIII.—ON THE PROPER WATERWAY FOR BRIDGES.

The most difficult part of an architect's task is, very often, to determine the amount of opening or waterway to be given to a bridge. When the banks are well defined and the river does not overflow, then the question is comparatively easy; but when, as with our Indian rivers, the dry-weather supply is a mere rivulet, or perhaps nothing, and the rainy-season supply a flood spreading over the country, then the question becomes one of very intricate calculation, inasmuch as it is difficult to determine what portion of the water is moving and what is mere back-water. It is seldom that the architect has opportunities of seeing the highest floods; he therefore gathers his accounts from others; or even if he should happen to witness a flood, he may not possess the means of measuring the sections and velocities.

2. An approximate calculation will shew a simple mode of making a useful estimate of the quantity of waterway that should be allowed.

3. Let A B (fig. 15) represent the flood-line of a river; it is plain that if we measure

Fig. 15.



the areas of each compartment, $x\, y\, z$ and s, and ascertain with what velocity the water is moving through each, we shall know how much water actually passes by in a given time, say a minute or a second.

4. Now as water flows on account of the slope in the river's bed, if we know the velocities caused by certain slopes, we can calculate what amount of opening must be given to a bridge, to allow the whole of the water of the above section to pass under the bridge at its natural velocity, and so avoid all that *heading up* which is found so destructive.

5. The *safest* width of opening would, in many rivers, be inconveniently great; we are therefore obliged to run some risk by confining the floods to narrower bounds, and this causes a heading up or 'afflux;' and in proportion to the perpendicular height of this afflux, so will the velocity be.

6. Table III. shews that sand is moved by the smallest velocities, even so little as 6 inches per second, or about one-third of a mile per hour; therefore the beds of our rivers must be continually moving, and the question becomes 'to what depth does this movement extend under certain velocities of current?'

7. Experience alone is our guide in replying to the above question; but I regret to say that until very lately, little or no attention had been paid to the subject. From certain data, I calculated the flood mentioned at par. 22, Section VII., to have been about 11 feet per second; and as the effect of this velocity was to scoop out the sand to a depth of 25½ feet, it is plain that any velocity approaching to 11′ per second must not be risked, under ordinary circumstances: I consider a velocity of 5 or 6 feet per second to be dangerous to bridges whose foundations do not rest on firm soil, or which are not carried to very great depths, and this velocity is caused by an afflux or heading up of only 6 inches.

8. The above may appear a small velocity to cause so much damage. Nature has,

however, afforded us some clue even in this difficult computation. Captain Sharp, in boring the bed of the Jumna at Agra, came upon broken *bricks* at a depth of 23 feet, and this can only be accounted for by supposing that the bed has been disturbed to that depth by the natural current of the river. Captain Sharp roughly estimates the surface velocity of the Jumna at Agra to be 8 feet per second at high floods, but from certain data, I do not calculate the *mean* velocity to be more than $5\frac{1}{2}$ or 6 feet per second, and this velocity is caused by the confinement of the flood between two bold banks only 1300 feet apart. The velocity of the greatest flood at Delhi is, probably, much less than 6′ per second.

9. In Table No. II. is given the amount of afflux caused by obstructions in the river's course, and in Table No. IV. the velocities due to those affluxes. If, therefore, the section of the river and its velocities can be accurately measured, the amount of waterway in the bridge, so as not to cause a greater velocity than 5 feet, nor a greater afflux than 5 inches, can be at once taken from those Tables.

10. I have said that very few architects ever have the opportunity of seeing the river in question at its floods; it may then be asked, how can the velocity and discharge be ascertained?

11. Determine by inquiry the height of the highest flood ever known, and correct the information, if possible, by flood-marks.

12. Take an accurate section of the river's bed perpendicularly to the course at the site of the proposed bridge, and calculate the area contained between the highest flood-line and the bed. Do the same at points 1 mile above and 1 mile below the proposed site of the bridge.

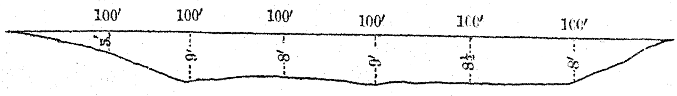
13. Measure the length of the undulating line of the river's bed (in each cross section), and divide the area by this length; the quotient will be what is called the 'hydraulic mean depth,' which will be found to vary very slightly from the common mean depth in most Indian rivers.

14. Add together the three mean depths so found, and divide by three; the quotient will be the *mean* of the three 'hydraulic mean depths' to be used in the calculations: write it in inches.

15. Ascertain, by means of a levelling instrument, the difference of level between the upper and lower section; that is, the amount of slope in the river's bed for 2 miles, and write it down in inches.

16. Multiply the hydraulic mean depth in inches by the difference of level just found (also in inches), and take the square root of the product, which will be the surface velocity of the current per second, in inches. Nine-tenths of the surface velocity may be taken as the 'mean velocity.'

17. Knowing the area of the section, (the mean of the three areas should be used,) we can by reference to the Table No. II. ascertain the afflux which will be caused by damming up one-third or one-fourth, &c. of the natural area, or waterway, thus:



The area of this section is 4600, and if the length measure 710 feet, then $\frac{4600}{710} = 6{\cdot}48$ feet, the hydraulic mean depth.

18. Let us suppose that the two other mean depths were 6·8 feet and 6·1, then $\frac{6{\cdot}8 + 6{\cdot}1 + 6{\cdot}48}{3} = 6{\cdot}46$, which is the *working* hydraulic mean depth; and in inches it will be 77·52.

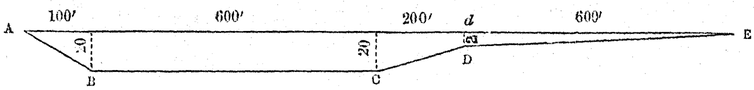
19. Say that the difference of level between the upper and lower sections is 30 inches; then, $\sqrt{77 \cdot 52 \times 30} = 48 \cdot 2$ inches, which is the surface velocity, and $48 \cdot 2 \times \frac{9}{10} = 43 \cdot 38$ inches, or 3·6 feet, the mean velocity in feet per second.

20. Say that we had proposed to have a bridge of three arches, each of 50 feet span, springing at a height of 9 feet above the bed of the river, then $3 \times 50 \times 9 = 1350$ represents the area of the waterway; and this is between two and three-tenths of the whole mean area of sections; therefore the *obstruction* will be equal to 7 or 8-tenths.

21. Now enter Table No. II. with the velocity of 4 feet, which is nearest to 3·6, and run the finger along until you come under the column 7-10ths, and you will find the afflux to be 3·2755 feet; and in the next or 8-10ths it is marked as 7·775 feet; take the mean, and call the afflux 5·5, and on referring to Table No. IV. you will find the corresponding velocity to be between 17 and 19 feet per second; which would tear up all but rock.

22. To find the safe afflux, viz. 5 inches, the corresponding velocity is ·53; therefore enter Table No. II. with the velocity 4 feet, and passing the finger along till you come to ·5759, you will find the corresponding amount of obstruction to be 4-10ths: the waterway, therefore, must be equal to 6-10ths of the area, and as the spring of the arches is 9 feet high, $\frac{4600}{9} \times \frac{6}{10} = 306$ is the length of the waterway required; and if 50-feet arches are preferred, it will require six of them instead of three.

23. I have shewn the general principle for ascertaining the proper opening for a bridge, but as all hydraulic formulæ have been computed for rivers of tolerable regularity of section, the application of the above principles to our Indian rivers will require modification. Suppose a river to have the following section—



the area of the whole is 15,800 square feet, the hydraulic mean depth is 10·5, or 126 inches. Suppose also the fall in 2 miles to be 10 inches, then $\sqrt{126 \times 10} = 36''$ or 3 feet; and $15800 \times 3 = 47400$ is the discharge in cubic feet per second, according to the general rule.

24. But if we take the section in two parts, viz. A B C D d as one, and the triangle E D d as the other, and calculate them separately, we shall find a considerable difference between this result and that of our first computation, thus:

25. The area A B C D $d = 15200$; the hydraulic mean depth is as nearly as possible equal to 20 feet or 240 inches: then $\sqrt{240 \times 10} = 49$ inches, or 4 feet, nearly; and $15200 \times 4 = 60800$ cubic feet per second is the discharge for the one portion alone.

26. The triangular portion has an area of 600 square feet; the hydraulic mean depth is 1 foot or 12 inches; then $\sqrt{12 \times 10} = 11$ inches, nearly, the superficial velocity: and $600 \times \frac{11}{12} = 550$ cubic feet, the discharge per second: therefore $550 + 60800 = 61350$ is the discharge, instead of 47400, as in the first computation.

27. I have adopted the superficial velocities in these illustrations, but in practice the mean velocities should be used.

28. The architect must use his discretion in calculating different rivers. Some may be taken by the first rule; others may require three or more separate computa-

tions or divisions. The calculations belong to plain arithmetic, and with this view I have selected the formulæ of Dr. Eytelwein, a German philosopher, in preference to those by the French Academicians, which are rather abstruse, and are not, I think, one jot more accurate when applied to open rivers. Persons desirous of studying the subject more deeply would do well to consult the 'Encyclopædia Britannica,' or Robison's 'Mechanical Philosophy.'

SECTION IX.—GENERAL OBSERVATIONS.

Position of a Bridge. Site.—The general situation of a bridge will be determined by the line of road which it is intended to carry, but its exact site should be selected, as much as possible, in conformity with the following views:

1. Bold banks are to be preferred with Indian rivers, as involving less expense in the matter of causeway approaches, and as rendering the direction of the stream more certain.

2. The middle of a straight reach (with regard to flood-stream) should be selected; as, in bends of a river, one bank is under continual erosion, therefore the abutment on that bank would be in danger of being turned by the current.

Number of Arches.—As a general principle, it is better to make few arches of large span than many arches of small span, as involving less trouble in the foundations, and as affording freer passage for floods. Thus a river is more obstructed by two arches of 25 feet each than by one arch of 50 feet span.

Ornament.— Solidity and durability should on no account be sacrificed to appearances. Thus, when brickwork is used, the parapets should be formed of plain panelled masonry, in preference to balusters of pottery.

The arch itself should always be indicated or relieved in some manner, otherwise the opening will look like a hole cut in a wall. In brickwork, this may be done by projecting the arch face 4″ or 6″ beyond the surface of the rest of the masonry, when it may be chiselled into voussoirs or into fillets.

Pillars or pilasters, with entablatures, have been exploded by good taste.

TABLE I.

aily Progress and Cost in undersinking the Block Foundations of the Indree Suspension Bridge, communicated by Captain W. E. Baker, Superintendent, Canals west of Jumna.

Feet.	Front Abutment. Blocks 12′ 3″ × 10′ 0″, with 4 shafts in each.				Total.	Average.	Cost of sinking 100 sq. ft. of Block, in Nos. 1, 2, 3, and 4.			Flank Blocks 12′ 0″ × 8′ 0″, with 2 shafts in each.				Total.	Average.	Cost of sinking 100 sq. ft. of Block, in Nos. 5, 6, 7, and 8.		
	1	2	3	4						5	6	7	8					
	Days.	Days.	Days.	Days.	Days.	Days.	Rs.	As.	P.	Days.	Days.	Days.	Days.	Days.	Days.	Rs.	As.	P.
1	0·5	0·5	0·5	0·5	2·0	0·5	1	7	8	0·5	0·5	0·5	0·75	2·25	0·5625	1	4	5
2	0·75	0·75	0·5	0·5	2·5	0·65	1	13	7	0·75	0·75	0·5	0·75	2·75	0·6875	1	9	0
3	0·75	0·75	0·75	1	3·25	0·8125	2	6	6	0·75	0·75	0·75	0·75	3	0·75	1	11	3
4	2	1·75	0·75	0·75	5·25	1·3125	3	14	2	1·75	1·5	0·75	0·75	4·75	1·1875	2	11	2
5	0·75	1	1	1	3·75	0·9375	2	12	5	1	1	1	1	4	1	2	4	4
6	0·75	0·75	1	1	3·5	0·875	2	9	5	1·25	1	1·5	0·75	4·5	1·125	2	8	10
7	0·75	1	1	1	3·75	0·9375	2	12	5	1·5	2	1·5	1·5	6·5	1·625	3	11	0
8	0·75	0·75	0·75	0·75	3	0·75	2	3	6	2	2	1·25	1·25	6·5	1·625	3	11	0
9	0·75	0·75	1·5	1	4	1	2	15	4	1·5	1	1·5	1·5	5·5	1·375	3	1	11
10	1	0·75	1	1·5	4·25	1·0625	3	2	4	1·5	1·25	1·5	1·25	5·5	1·375	3	1	11
11	1	0·75	1·25	1·5	4·25	1·125	3	5	4	2	1·75	1·75	1·75	7·25	1·8125	4	1	10
12	2	1·25	2	1·75	7	1·75	5	2	11	2	2	2	2	8	2	4	8	8
13	1·25	1	1·5	2	5·75	1·4375	4	4	1	1·75	2	1·5	1·5	6·75	1·6875	3	13	4
14	2	2	2	2	8	2	5	14	9	2	2	2	1·75	7·75	1·9375	4	6	5
15	2	2	2	2	8	2	5	14	9	2	2·5	2	1·75	8·25	2·0625	4	10	11
16	2	2·5	2	2	8·5	2·125	6	4	8	2·5	3	2·5	2·5	10·5	2·625	5	15	4
17	1·5	3	2	2·25	8·75	2·1875	6	7	8	2	3·5	2·5	2	10	2·5	5	10	10
18	2·5	3	3	2·25	10·75	2·6875	7	15	4	4	5	4	4	17	4·25	9	10	5
19	2·5	3	3	2·5	11	2·75	8	2	3	4·5	5	4·5	4	18	4·5	10	3	6
20	3·5	3	4	2·5	13	3·25	9	10	0	5	6	4·5	5	20·5	5·125	11	10	2
21	4	3	4	3	14	3·5	10	5	10	5	5	5	4	19	4·75	10	12	7
22	3	4	4	3·5	14·5	3·625	10	11	9	5	7	5	5·5	22·5	5·625	12	12	5
23	4	4·5	3	2·75	14·25	3·5625	10	8	9	5·5	5	5·25	7	22·75	5·6875	12	14	8
24	4	4	3·5	2·75	14·25	3·5625	10	8	9	4·5	5	5	4	18·5	4·625	10	8	0
25	6	3	3	3	15	3·75	11	1	8	4·5	5	5	4·5	19	4·75	10	12	7
26	4	4·5	3·5	3·5	15·5	3·875	11	7	7	5·75	8	6	6	25·75	6·4375	14	9	11
27	4·5	6	5·5	5	21	5·25	15	8	9	7·5	6	9	7	29·5	7·375	16	11	7
28	6·5	6·5	5	4·5	22·5	5·625	16	10	6	7·5	7	6	10·5	31	7·75	17	9	3
29	5·5	7	4·5	4·5	21·5	5·375	15	15	8	16	8·5	10	8	42·5	10·625	24	2	0
30	6	5	7	5	23	5·75	17	9	5	12	6	10·5	9·5	38	9·5	21	9	2
31	6·5	6	6	5	23·5	5·875	17	6	4	12	12	15	12	51	12·75	28	15	3
32	10	9	13·5	12	44·5	11·125	32	15	1									
33	12	10·5	13	14	49·5	12·375	36	10	3									

tal cost of sinking 4 abutment blocks, Nos. 1, 2, 3, 4 (12′ 3″ × 10′ 0″ × 4 = sq. ft. 490) = Co.'s rs. 1431 1 3

Ditto 4 flank blocks, 5, 6, 7, 8 (12′ 0″ × 8′ 0″ × 4 = sq. ft. 384) = „ 868 8 7

abutment blocks, 490 square feet, in 98·625 days, cost 1431 1 3: therefore 100 sq. ft. in 1 day cost 2 15 4½

flank blocks, 384 square feet, in 99·6875 days, cost 868 8 7: therefore 100 sq. ft. in 1 day cost 2 4 4

ain, 490 square feet (1431 1 3) : : 100, cost 292¼, nearly, for sinking 33 feet, or 8·85 per ft. in depth.

, 384 square feet (868 8 7) : : 100, cost 226·17, nearly, for sinking 31 feet, or 7·3 per ft. in depth.

B.— In considering this Table, it must be remembered that the last few feet in depth are greatly raised above the average, on account of the work being carried into the more solid stratum or footing course; therefore, in applying the Table to greater depths, the last few feet should be reserved as an after-addition to the quotient.

TABLE II.

Amount of Obstruction compared with the virtual Section of the River.

Velocity of current, in ft., per second.	1-10th.	2-10th.	3-10th.	4-10th.	5-10th.	6-10th.	7-10th.	8-10th.	9-10th.	
	Proportional Rise of the River, in feet.									
1	·0157	·0377	·0697	·1192	·2012	·3521	·6780	1·6094	6·6389	
2	·0277	·0665	·1231	·2108	·3548	·6208	1·1955	2·8378	11·7058	Ordinary floods.
3	·0477	·1144	·2118	·3618	·6107	1·0687	2·0580	4·8850	20·1504	
4	·0760	·1822	·3372	·5759	·9719	1·7008	3·2755	7·7750	32·0720	
5	·1165	·2793	·5168	·8782	1·4895	2·6066	5·0202	11·9160	49·1535	
6	·1558	·3736	·6912	1·1807	1·9925	3·4868	6·7154	15·9398	65·7518	Violent floods.
7	·2078	·4983	·9221	1·5750	2·6578	4·6511	8·9578	21·2626	87·7080	
8	·2578	·6423	1·1884	2·0299	3·4255	5·9947	11·5454	27·4042	113·0422	
9	·3359	·8054	1·4903	2·5566	4·2956	7·5172	14·4777	34·3646	141·7541	Unusually violent floods.
10	·4119	·9877	1·8726	3·1218	5·2680	9·2190	17·7557	42·1440	173·8440	

Example.—The breadth of the Thames is 926 feet. The sum of the waterways, old London Bridge, was 236 feet. The amount of obstruction, therefore, was about ·75 of the entire section; so that a velocity of 3½ feet per second would give a fall of nearly 4·75 feet, agreeing with the actual result.

TABLE III.

Table of Effects of Running Water on Soils.

Velocities.		Effects.
Inches per second.	Miles per hour.	
3	0·170	Will work upon fine potters' clay.
6	0·340	Will lift fine sand.
8	0·454	Will lift sand, coarse as linseed.
12	0·683	Will sweep along fine gravel.
24	1·363	Will roll rounded pebbles 1″ in diameter.
36	2·045	Sweeps angular stones the size of an egg.

N. B.—The velocity at the bottom must be found for comparison with this Table.

TABLE IV.

Table of Velocities due to certain Heights of Head-Water or Afflux.

Height of Afflux. Feet.	In.	Velocity per second. Feet.	REMARKS.
0	1	2·30936	
0	2	3·2659*	* Sweeps angular stones, the size of eggs.
0	3	3·5650	
0	4	4·6186	
0	5	5·1640	
0	6	5·6569	
0	7	6·1101†	† Probable velocity of floods of Jumna at Agra, where the bed has been deranged to the depth of 23 feet. Large volumes of water are required to produce this effect.
0	8	6·5320	
0	9	6·9282	
0	10	7·3029	
0	11	7·6942	
1	0	8·0000	
1	3	8·9443	
1	6	9·9797	
1	9	10·584	
2	0	11·314‡	‡ Scooped sand to depth of 23 feet.
2	3	12·028	
2	6	12·649	
2	9	13·266§	§ Scooped out a gravel bed under Smeaton's Hexham Bridge, on the Tyne, by some account.
3	0	13·856	
4	0	16·000	
5	0	17·889‖	‖ Mr. Smeaton himself said 5′ head-water.
6	0	19·596	
7	0	21·166	
8	0	22·627	
9	0	24·000	
10	0	25·298	

TABLE V.

Natural Cotangents to Radius 1.

Deg.	Cotangents.	Deg.	Cotangents.	Deg.	Cotangents.
1	57·28996	31	1·66428	61	0·55431
2	28·63625	32	1·60033	62	0·53171
3	19·08114	33	1·53986	63	0·50952
4	14·30067	34	1·48256	64	0·48773
5	11·43005	35	1·42815	65	0·46631
6	9·51436	36	1·37638	66	0·44523
7	8·14435	37	1·32704	67	0·42447
8	7·11537	38	1·27994	68	0·40403
9	6·31375	39	1·23490	69	0·38386
10	5·67128	40	1·19175	70	0·36397
11	5·14455	41	1·15037	71	0·34433
12	4·70463	42	1·11061	72	0·33492
13	4·33147	43	1·07237	73	0·30573
14	4·01078	44	1·03553	74	0·28674
15	3·73205	45	1·00000	75	0·26795
16	3·48741	46	0·95569	76	0·24933
17	3·27085	47	0·93251	77	0·23087
18	3·07768	48	0·90040	78	0·21256
19	2·90421	49	0·86929	79	0·19438
20	2·74748	50	0·83910	80	0·17633
21	2·60509	51	0·80978	81	0·15838
22	2·47509	52	0·75355	82	0·14054
23	2·35585	53	0·73128	83	0·12278
24	2·24604	54	0·72654	84	0·10510
25	2·14451	55	0·70021	85	0·08749
26	2·05030	56	0·67451	86	0·06993
27	1·96261	57	0·64941	87	0·05241
28	1·88073	58	0·62487	88	0·03492
29	1·80405	59	0·60086	89	0·01745
30	1·73205	60	0·57735	90	INFINITE.

PART III.—PERMANENT BRIDGES.*

SECTION I.—STONE BRIDGES.

Ever since the construction and properties of the arch began to be understood, stone has been the material in most general use for bridges of any size and importance.

Forms of arches.

The full or semicircular arch was the one formerly most common; but now that it is considered desirable to lessen the ascent of the roadway of a bridge, the flat segmental, the elliptical, and the oval are usually employed. Of these, the latter is the form which admits of the greatest waterway with the same span and rise. It is formed of several arcs of circles, usually about five, of which the curve at the springing lines should be less than that of the ellipse, and the radius of the arc at the crown should not be more than one and a half times the span.

Span.

Foundations.

The form of the arch or arches, and the number of piers, having been decided on, the work is commenced by excavating for the piers and abutments, till a solid foundation is obtained either on the rock or hard gravel; or should the soft earth descend to any depth, it will be necessary to drive piles and spike planking upon them, or else to fill in the whole space with concrete: sometimes both piling and concrete are employed. The ordinary mode of laying the foundations of the piers is by means of a coffer-dam enclosing the whole space of the footings, but it is sometimes accomplished by sinking caissons or frames filled with stone or brick; and of late the diving-bell has been often used.

Radiating Foundations.

Plate I. fig. 1.

Each abutment has to bear the weight of half an arch with its roadway, and in addition must be sufficiently strong to counteract the horizontal thrust, which may, however, be almost entirely avoided by commencing the radiating or skew-back courses from the very foundation, the rock being cut something in the form of the skew back of an ordinary arch. This method is followed in the bridge of the Rialto at Venice, and the Grosvenor Bridge over the Dee at Chester. When this is done where the soil is such as to require piling, the piles should be driven in a direction perpendicular to the lowest radiating course, the thrust from which would otherwise be apt to force them in a lateral direction through the yielding earth around them. Driving the piles thus would undoubtedly be at first difficult, and consequently expensive, but it has been done, and may be made an easy operation by having a machine for the purpose.

Abutments.

Abutments are usually formed with counterforts, and when extending any distance they often have land arches constructed in them, to lessen the quantity of material. On railways these side arches are very useful as giving the means of viewing the line for some distance in advance.

In large arches the abutments and piers should be entirely faced with cut stone. The filling in or backing should be of large rubble, carefully laid and well grouted at every two or three courses. The upper courses should be of large blocks of cut stone, well cramped and bonded. All cramps in stonework of importance should be of copper, as iron corrodes and becomes loose. If the abutments extend far into the stream, the waterway should be gradually lessened by means of water-wings built out in a curved form from the bank to the back of the abutment.

Piers.

Each pier has to support the weight of two semi-arches, but no horizontal thrust, which is counteracted or destroyed by the two opposing arches. The least thickness of a pier at top must of course be twice the depth of the voussoirs at the springing

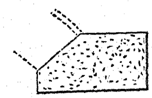
* Compiled by Lieut. Binney, R.E.

line, but in practice they are generally made much thicker, to allow for ordinary wear from the waves, bad workmanship, and other casualties. The foundations of the piers are formed in offsets, on which the feet of the centres are supported while the arches are being built. The piers and starlings generally have either a rectilinear or curved batter. The latter project about half the thickness of the pier, and are carried up to the highest water-line, and finished above with a single stone or saddle-backed coping, called a 'hood.' They are built of the same materials as the piers, of which they are simply continuations, either in a triangular or parabolic form, to lessen the backwater and permit the stream to pass through more freely.

Starlings.

Skew backs.

When the radiating courses are not carried down to the foundations of the abutments, and at all times in the piers, it is necessary to form the skew backs of blocks of stone cut as in the annexed figure, and well cramped to the other work, to prevent their slipping.



Centres.

When the Engineer has arrived at this point, he may proceed with the arch or arches, having first arranged his centres, which should be constructed during the building of the piers. This is not the place to give a lengthened description of the different forms of centre in use, but it will be well to offer a few remarks on the subject. Some Engineers give the centre a slight increase in rise over the intended arch, in order that a settlement may not cause the crown of the arch to sink below the level originally intended. In building the bridge over the Dora Riparia at Turin, Mosca made the rise of his arch 18·0446 feet, and that of the centre 18·9015 feet, the span being 147·6 feet; and on the completion of the work, the soffit of the key-stone was only $2\frac{1}{8}$ inches above the intended height. The centre used for Chester Bridge consisted of four distinct sets of radiating struts supported on trestles, the wedges being carried on the outer rim in such a manner as to admit of easing the different parts of the arch as required, to prevent undue settlement. This form has the disadvantage of obstructing the opening between the piers in rivers much navigated. In centres of the ordinary forms, with the double wedges placed under each rib, the most serious consequences have resulted from the men being obliged to go underneath to ease the arch; but this may be avoided by making the wedges run the whole length from one outer rib to the other, so that they may be eased by men on each side without danger. For a bridge of three arches, two centres are required; and for one of five arches, three centres.

Trans. Inst. C. E. vol. i.

Arrangement of arch-stones.

The planes of the arch-stone joints must be perpendicular to the curve of the soffit. The stones are laid in straight lines from one face of the arch to the other, bounded by parallel lines called 'bed joints;' the line of stones being called a 'course' or 'string-course.' The joints in the transverse direction are called 'cross-joints,' and are not continued throughout, but break joint in the adjacent string-course, to prevent lateral disruption. Various modes have been adopted with the view of preventing the voussoirs slipping on one another. Old arches have been found of the annexed forms, and in fig. 4 (Blackfriars' Bridge) the voussoirs are united by means of joggles

Methods of connecting voussoirs.

Figs. 1 and 2.

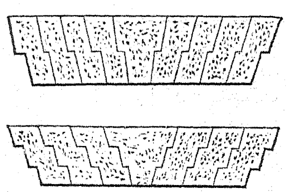


Fig. 3.

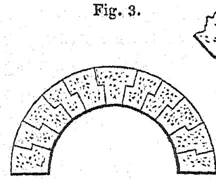
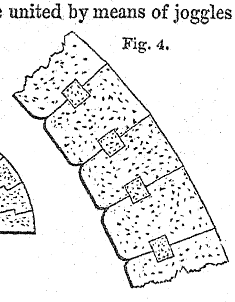


Fig. 4.



consisting of a cubic foot of hardstone, let half-way into each joint. The mortar should be thin and well tempered, and when the stones are all laid, the joints at the back should be examined, and, if open, filled with pieces of slate and grouted.

Lead to prevent unequal settlement. See Trans. Inst. C. E.

To prevent the joints opening or the stones cracking on removing the centre of the Chester Bridge, the course above the springers was laid on a wedge of lead $1\frac{1}{2}$ inch thick on the face, running to nothing at the end of the bed, and thin strips of lead were introduced in all the joints, over about two-thirds of the soffit, to where the pressure was supposed to change to the back of the arch-stones. "In setting the key-stones, three thin slips of lead were hung down on each of the stones between which they were to be inserted, and the key-stone, being besmeared with a thin putty of white lead and oil, was driven down with a small pile engine." Thus the whole bridge settled without any derangement or injury, the soft and yielding nature of the lead causing the pressure to spread equally over the surface of the joints. Sometimes the edges of the voussoirs are bevelled off a little to prevent chipping.

The key-stone is generally from $2\frac{1}{2}$ to 4 feet in depth, and the arrangement of the remainder of the voussoirs made to conduce to the general effect; thus, when the whole facing of the bridge is of cut stone, the top joints of the voussoirs are usually formed in steps corresponding with the horizontal joints of the backing; and when the spandril facings are of rubble or brick, the voussoirs are generally made of equal or alternate depths.

Spandrils.

The spandrils should be built of hammered stone or the best rubble. They are usually raised to about one-fourth of the rise above the piers, and in some bridges are constructed of cut stone, the lower courses being horizontal, and the top forming an inverted arch.

Capping.

The capping of arches should be of flags laid with the bond well formed, or else of concrete, to prevent water soaking through, and should be laid so as to form gutters over the piers, where the water from the roadway is received and carried off by iron pipes through the piers into the river above low-water mark.

Head-walls.

The head-walls are usually faced with cut stone filled in between with rubble or small arches to support the roadway; earth was formerly used, but requires a much greater thickness of wall.

Cornice.

A cornice is placed immediately on a level with the top of the key-stone as a coping, to protect the facing from rain; its form must be plain or moulded, according to the size or style of the bridge. It should be formed of large single blocks of stone, and the joint between it and the foot of the parapet should be above the level of the footpath, to avoid the wet settling in it.

Parapet.

The parapet or balustrade should be about 4 feet high, and made to conform to the general architectural effect of the bridge, the exterior finish of which must depend mainly on its position, but should, as a general rule, have a strong solid appearance. This appearance is very much diminished by making a bridge perfectly flat, and it has been considered by many eminent Engineers that 1 in 24 is a very good ascent for the roadway.

Approaches.

The approaches must be so formed as to make the bridge safe and easy of access. When the roadway is but little raised above the natural ground, it is enough to carry out the head-walls a little way into the bank, and face the embankment with dry stone or sodwork; but when there is more than one approach, and the road is much raised, the access must be widened, and wing walls built out from the bridge to support the embankment. These wing walls are either formed by prolonging the head-walls in a curve outwards to the edge of the embankment, or building a straight wall forming an angle with the head-wall. In both cases the wall and parapet are continued down to the foot of the embankment, either in a slope or in steps.

Fig. 1, Plate II., is a longitudinal section of part of Waterloo Bridge, shewing the

Fig. 1, Plate II. centering. V represents the voussoirs; P, the parapet; I, inverted arch over the spandril courses; B, the walls of brickwork on which the flags (Q) are supported, carrying the roadway material: *a a* are the striking-plates of the centre; *b*, the easing wedge; *c c*, struts; *s s*, stirrups or suspenders in pairs; *i i*, cast-iron sockets to receive the ends of the struts; *p p*, main props resting on the feet of the piers.

Fig. 2. In fig. 2, S is the starling, and H, the hood or cap; D, the spandril. This figure is a longitudinal section of the bridge of Neuilly.

Fig. 3. Fig. 3 is a section through the crown of the arch.

SECTION II.—BRICK BRIDGES.

Many of the old bridges were built of brick, but it is now generally confined to those of small span, as canal and railway bridges. The same general observations apply to these as to stone bridges. The most simple mode of forming the arch is to lay the bricks in half-brick rings, with the joints very close on the under side, taking advantage of the difference in their dimensions to prevent two joints coming above one another. In this case two or three rings are carried on together. Another way is to lay two or three rings of brick on end; but this method is very weak, the only key being formed by the mortar or cement.

The utmost caution should be observed not to lay a single brick until it has been well saturated with water, as it will otherwise deposit a coat of sand on the cement, and soon become detached from it.

In a circular segmental arch, it is well to mark the centre by battens carrying a small fixed pulley, round which a line is passed for the purpose of laying the outside bricks of each course at their true angle.

The mode of laying the bricks in half-brick rings is thought by many to be very weak from having no bond between the soffit and back of the arch; and hence the following has been recommended as the means of giving strength and bond both ways. The arch should be divided in portions by joints running through to the back, the bricks being laid alternately in shells and in blocks, with the joints running through.

Plate III. fig. 1. A, B, shells. C, block. D, key.

If the arch is not more than 3 feet thick, the thickness may be divided into two equal shells laid in rings, and the thorough blocks should not be more than three or four bricks thick on the curve of the soffit, with the bricks laid on end. The bricks forming the key require to be laid with great care. The soffit course may be formed of a thickness of three bricks laid on end, the next of five, and so on, forming continuous joints.

Grouting. In all brick arches it is well to lay the second course above the soffit of the key in thin mortar or grout, and to wedge with pieces of slate. The grout may be used by dividing the length of the course into several compartments by bricks laid in mortar, and then pouring in the liquid, which should also be poured over the whole of the arch and abutments.

Railway Bridges. Plate III. fig. 2. A number of different drawings of railway bridges are given in vol. viii. of the Professional Papers, in one of which (Plate XXIX. fig. 5) the abutments are built in the form of large skew backs, somewhat similar to those of the Chester Bridge, described in the section on stone bridges, and partly supported by piles driven obliquely, as recommended in the same section. This bridge is of brick, with stone foundations and facing. A section of the abutment is shewn in Plate III. fig. 2.

Fig. 3. The arches on which the Blackwall Railway is supported, and which appear to bear a large amount of traffic without injury, are circular segments of 30 feet span and 10 feet rise, and are composed of five half-brick rings, with piers 3 feet 6 inches thick. The width of the arches is 26 feet.

It often happens, over or under railroads and canals, that a bridge cannot be built at right angles to the stream or road under it. Bridges of this form are called oblique or skew bridges, the bricks being laid diagonally instead of perpendicular to the faces. (Plate III. fig. 4.)

Bridges are often constructed of brick with stone skew backs, voussoirs, string-courses, and copings. Sometimes the parapets are formed of wooden posts and rails, instead of solid material; and in this case they are built out on corbels beyond the face of the bridge, thereby saving 1 or 2 feet thickness of masonry, and gaining that additional space for the roadway. Iron rails appear better adapted to the purpose, and are sometimes used. They may be made, at a trifling expense, to conduce very much to the ornamental appearance of the bridge.

Oblique Bridges, from vol. viii. Prof. Papers.

On the Birmingham Railway a bridge is built over a road at an angle of 32°. The arch is 21 feet span on the square, or at right angles to the road beneath it, and 39·627 on the face. The acute angle of the voussoirs is cut off at right angles to the face, and the cutting is gradually diminished to the opposite or obtuse quoin, where it vanishes, leaving no angle less than a right angle on the surface of the work.

On the Midland Counties Railway a bridge is built with parallel ribs of brickwork, about 4 feet broad on the square, elliptical, and 42 feet 6 inches span, with a rise of 11 feet. The plan of the abutment thus presents a series of steps, from which the ribs spring. This construction, however, in cases of great obliquity, requires either very thick arches or narrow ribs of brickwork, unless spandrils are introduced to fill up the spaces between the soffit of one rib and the extrados of another. Thus extra expense is incurred.

Sometimes, in oblique arches, the central part is built as a square arch, springing at right angles from the abutments, and the ends left at the acute angle on either side are filled in with courses, the beds of which are worked as for part of a true elliptic arch.

The following Table comprises brick bridges with wooden parapets.

Tables. Prof. Papers.

TABLE A.

Brick Bridges over Cuttings; 30 feet wide clear between railings; arches 30 feet span, 1 foot 6 inches thick.

Depth of Cutting, or Height of Bridge.	Excavation.	Concrete.	Brickwork.	Stonework.	Woodwork.
feet.	cubic yards.	cubic yards.	cubic yards.	cubic feet.	cubic feet.
14	98	60	330	402	42
30	112	100	530	465	124
60	915	180	1730	924	280

The following Table shews the difference in the quantity of material required for bridges in embankments and in cuttings.

TABLE B.

Brick Bridges in Embankments; width and span as before; thickness of arch 1 foot 10½ inches.

Height of Embankment or Bridge.	Excavation.	Concrete.	Brickwork.	Stonework.
feet.	cubic yards.	cubic yards.	cubic yards.	cubic feet.
19	158	80	405	478
30	278	140	545	395
50	314	157	2290	682

The great quantity of stone in the 19-feet bridge was required for coping to wing walls, which the other bridges have not got. A tunnel bridge, with an arch 2 feet 3 inches thick, in a 40-feet embankment (slopes $1\frac{1}{2}$ to 1), contains 295 yards of excavation, 148 yards of concrete, 751 yards of brickwork, and 653 feet of stonework.

The following is an abstract taken from designs of oblique bridges.

TABLE C.

Brick Bridges in Embankments, at various Angles of Obliquity. Dimensions as in Table B.

Height of Embankment or Bridge.	Angle of Obliquity.	Brickwork.	Stonework.
feet.	°	cubic yards.	cubic feet.
30	80	1122	414
..	60	1198	860
40	80	2000	766
..	60	2394	792
..	40	2598	1017
..	30	3336	1227
50	80	2348	727
..	60	2616	1184

Most of these arches are semicircular, and the piers are, when practicable, lightened by arches in the width of the bridge.

Plate III. figs. 4 to 7.

Figures 4 to 7, Plate III., shew an oblique bridge of small width. Fig. 5 is a half-section; fig. 4 is a half-elevation; fig. 6, a plan above the foundations; and fig. 7 is a half-section taken on the square.

A bridge over a cutting may be built without a centre: one was built thus on the Birmingham and Gloucester Railway. The abutments being built up to the height of the springing, the earth was cut away to the form of the arch; seven rows of pegs were then inserted, shewing the proper curve; a line of 3-inch planks was laid across, and on them were laid battens on edge, gauged to the exact profile; the earth was consolidated, and a batten flooring laid over it. This bridge was constructed of small pieces of limestone.

SECTION III.—WOODEN BRIDGES.

Forms of Arches.

Wood was undoubtedly the first material ever used in the construction of bridges, the most ancient of which consisted simply of a rough log or tree thrown across a narrow stream or chasm. After a time these logs were squared, and either laid from one side to the other, or abutting end to end, or crossed on some kind of trestle. This afterwards gave place to timbers or girders trussed in various ways. In the present day wood is chiefly used where it is very plentiful, and economy is the main object, as is generally the case in the United States of America.

The modes of constructing wooden bridges are extremely varied. One of the worst is that in which the timbers are short, and abutting against one another in the form of a curb or Mansard roof; and the best are constructed of curved ribs of different forms according to the span.

Span 40 feet and under.
Plate V. figs. 4, 5.

For small spans* of less than 40 feet, with a rise of $\frac{1}{6}$th, the ribs may be formed by taking five or six pieces of 3-inch plank, 9 inches deep, abutting against each other,

* Tredgold.

with other pieces, 12 inches deep, crossing the joints of the first, and keyed to them with wooden keys. Two of these ribs with joists across will support an ordinary roadway.

Span 200 feet.

Plate IV. figs. 3, 4, 5.

For arches of 200 feet span,* the ribs should consist of pieces of scantling bent to the proper curve by steaming or otherwise. In figs. 3, 4, 5, the arch is composed of four ribs, each 18 inches thick and 4 feet deep, having two thicknesses in width and three or four in depth, according to the size of the scantling to be obtained. The joints are well scarfed, bolted, and keyed; and the vertical supporting pieces are notched on to the ribs in pairs, and bolted together like suspenders, and placed from 15 to 18 feet apart.

A cross tie is bolted to each side of the vertical pieces, and notched on to the ribs, both on the upper and under side.

Between the timbers carrying the roadway joists, diagonal braces should be framed to prevent lateral motion.

In stormy positions, or where very heavy loads are likely to pass, braces may also be framed with advantage here and there over the back of the ribs, which should not be more than 8 feet apart.

Plate IV. figs. 1, 2. Span 250 to 400 feet.

For a still larger span,* from 250 to 400 feet, it is best to construct frames each consisting of two ribs curved as in the last example. Radial pieces are notched on to the ribs like the vertical pieces in the last, and between these are crosses halved together in the middle, and abutting end to end between the radials.

The vertical roadway supports are connected with the radials, and at A B horizontal ties are notched and bolted to them to stiffen the work; and for the same purpose diagonal braces may be applied on the horizontal cross ties and also between the roadway bearers, and other braces may be framed in a few places between the rib-frames, as shewn by dotted lines.

Roadway.

To form the roadway, joists are laid across the bearers, and covered with 3 or 4-inch plank, and on this gravel is laid, either by itself or paved with blocks of stone. It should be about 18 inches thick in the middle, and 14 at the sides of the road, and means must be adopted for carrying off the wet.

As, however, the wet will soak through the paving or gravel, and injure the planking, some have only used a wooden roadway, laying a second tier of plank crossing the former one. This might, however, be avoided by covering the plank with some kind of asphalt, impervious to the rain.

Abutments of stone.

If practicable, stone should be used for the abutments and piers; but if wood is preferred, the best mode is to drive piles about 2 feet apart in the direction of the current, and to strengthen them by diagonal braces. When the water is deep, the piles should be cut just below low-water mark, and posts mortised into them and secured by bolts and straps. The latter method has this advantage, that thus the part below water, which does not decay so quickly, is separated from the upper part, which, being alternately wet and dry, is very perishable, and requires frequent repairs, and can by this arrangement be easily renewed.

Abutments, thickness.

Tredgold gives the following rules. To find the thickness of abutment necessary to resist the thrust of a timber arch,—take h = height of abutment; w = weight of a square foot of the arch; s = half the span; and R = the rise; then,

$$\frac{\left\{\sqrt{\left(\frac{160\,h^2}{w\,\mathrm{R}}+1\right)}-1\right\}s\,w}{120\,h} = \text{the thickness required.}$$

* Tredgold.

This is about one-fourth more than is absolutely necessary to resist the thrust, in addition to the weight of that part of the abutment above the springing.

To calculate the scantling of the arch-ribs, put w = width of bridge; s = half the span; R = the rise; and n = the number of ribs; then

$$\frac{w \times s^2}{\mathrm{R}n} \times 0{\cdot}0011 = \text{the area of the rib in feet when gravelled.}$$

Scantling of ribs. When only planked, take 0·0007 for a multiplier instead of 0·0011. This will be enough to bear the weight of the roadway alone, but $\frac{1}{3}$th more should be added, to allow for the additional strain occasioned by the passage of heavy waggons, or other causes.

Rise. The rise of a wooden arch must not be less than that given by the equation

$$\frac{s^2}{2\sqrt{h^2 - s^2}} = \text{the rise;}$$

where s = half the span, and h = the height of a column producing the same pressure on its base, as the greatest pressure that ought to be on the framing.

The following Table gives the least rise which may be given to different spans. A small rise requires a greater amount of material to give the same strength as a greater rise.

Span.	Rise.	Span.	Rise.	Span.	Rise.
30	0·5	120	7	280	24
40	0·8	140	8	300	28
50	1·4	160	10	320	32
60	2	180	11	350	39
70	2·5	200	12	380	47
80	3	220	14	400	53
90	4	240	17		
100	5	260	20		

Settlement. The settlement of wooden arches is given by Wiebeking as $\frac{1}{72}$; that is, a bridge of 144 feet span and 1 foot rise will become horizontal, and consequently for a final ascent of $\frac{1}{24}$ it must be framed to $\frac{1}{18}$.

Plate V. figs. 2, 3. Figs. 2, 3, Plate V., shew some of the modes of supporting wooden bridges, where the timbers are short and piers form no obstacle to the navigation.

Fig. 9 shews the form of a wooden pier.

Plate V. fig. 1. Suspended road-way. Fig. 1 is a form frequently adopted in America for bridges of great extent and with low abutments. The width of the bridge is divided by arches rising above the roadway, and to these are suspended verticals, either of wood or iron, which support the sleepers or girders on which the roadway is carried: the ends of the arcs are usually notched into the girders. Stevenson describes one of these bridges over the Susquehanna at Columbia. "It consists of twenty-nine arches of 200 feet span, supported on two abutments and twenty-eight piers of masonry. The waterway is 5800 feet, and the whole length, including abutments and piers, about $1\frac{1}{4}$ mile. It is supported by three wooden arcs, forming a double roadway. There are also two footpaths, making the whole breadth 30 feet. The arcs are formed of two pieces, each 7 inches wide by 14 deep, placed 9 inches apart; the beams by which the roadway is suspended being placed between them, and fixed by iron bolts passing through the whole."

Susquehanna Bridge.

Plate V. figs. 7, 8. Prussian arch. There is another kind of wooden arch employed in Prussia, composed of a beam with three or five saw-kerfs, by means of which it is bent to the required curve.

Fig. 6. Mode of bending. The mode of bending is described by Captain Nelson in vol. iii. of Professional Papers, as follows. "In this figure only three kerfs are shewn; it is more usual and advisable to have five. The centre kerf is first cut, reaching from the butt along $\frac{3}{4}$ths or $\frac{4}{5}$ths of the length; the saw is then returned on each side to complete the other two kerfs, which stop at 2 or 3 feet short of the butt. When five kerfs are made, the last two commence at L and end at G.

"The beam thus prepared is laid on the horizontal frame A B C, in the position I J.

"A B C is a frame of rough spars, halved into each other, and firmly picketed or otherwise fixed at the angles; E E′, any convenient number of smaller spars radiating from B, and halved into or otherwise secured to A C and D F; *c c′ c″ c″* cleats spiked down at points giving the intended curve.

"In bending the beam, the first thing to be done is to fix the butt very firmly at G, by means of pickets, double cleats *c c*, lashing, &c. Any convenient power, such as crab, block and tackle, &c., is then applied in a direction about parallel to E′ B; the rope or chain is fixed to H, and the beam is very gradually pulled down to the cleats *c′*, *c″*, *c‴*, in succession. As soon as the desired curve is obtained, the cleat *b* on B C is spiked down, and the beam lashed to the principal spars of the frame. The mortise I is next cut, and a tongue of wood harder than the beam is driven in. Lastly, the beam is hooped, at intervals of perhaps 2 feet, with iron collars, each closed with screw and nut, or with bolt and rivet. In ordinary cases these hoops should be of, say 2 in. × $\frac{1}{4}$ or $\frac{3}{8}$-inch flat iron.

"The beam thus hooped and mortised at I (which is an important part of the process) may be taken from the frame at once, without any fear of its altering its form.

"The cleats *c′ c″ c‴* can be fixed permanently to the spars E, and these last placed and secured according to circumstances. N. B. The natural tapering of the wood is always preserved, squared as baulk."

Plate V. fig. 10. Fig. 10 shews the form of Love's trussed girder, which may be applied to bridges, and a modification of which, constructed of iron, might be advantageously employed for the road bearers of suspension bridges, as recommended by the writer in the section on those structures.

Town's lattice. There is still another kind of bridge much used in America, viz. Town's patent lattice, consisting of a series of braces, inclined at rather more than 45°, with others crossing at the same angle, with a horizontal string-piece bolted on each side at top and bottom. The whole of the bolts are made of hardwood. The height of the truss is usually $\frac{1}{10}$th or $\frac{1}{12}$th of the span. The roadway may be either at top or bottom.

Fig. 5.

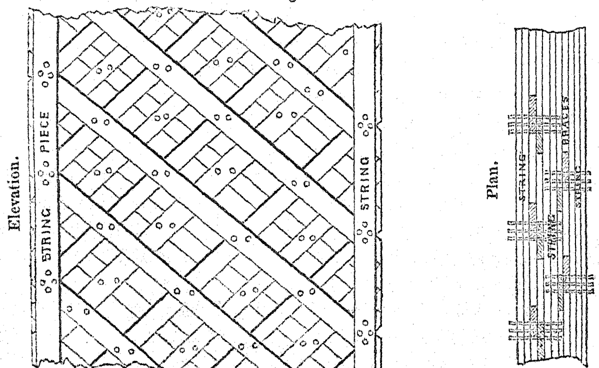


Plate V. figs. 11, 12. Figs. 11, 12, shew the form of an ice-breaker to be used in rivers subject to floating ice: it should be moored a short distance above the bridge, with the sharp point up stream.

SECTION IV.—IRON BRIDGES.

The principles of the construction of iron bridges are in many respects similar to those of wooden ones; that is, they are composed of several ribs kept in position and strengthened by distance-pieces, diagonal braces, &c.; and on these ribs are placed spandril standards supporting the roadway bearers.

Ribs. In small arches the spandril standards and the ribs may be cast together.

In some cases the ribs have been formed by crossing the joints of short plates of different widths, like the planks in wooden arches of small span; but usually the parts of the rib abut end to end, and are connected by flanges bolted firmly together.

Piers. The ends of the ribs are fixed to abutment plates bedded in the masonry skew backs.

The abutments and piers may be either constructed entirely of masonry, or else of masonry as high as the springing, and iron above. The masonry of the piers might be entirely dispensed with, and iron piles substituted, if some means were found by which they could be rendered incorrodible, which object may perhaps be attained by the process of galvanism, as lately applied to that purpose. Iron has, however, this disadvantage, that if one of the piles were struck by a heavy body, it would probably break and cause great danger to the superstructure.

Plates VI. & VII. Plates VI. and VII. represent the bridge erected by Telford over the Severn at Tewkesbury.

Trans. Inst. C.E. The arch is 170 feet span, 17 feet rise, and the roadway 24 feet in the clear, between the rail skirtings.

Foundations. The foundations of the abutments are supported on piles with sills spiked down to them, and the interior spaces filled in with rubble stone well rammed and grouted.

Land arches. From the springing-course up to the roadway, the structure consists of six arches with piers and pilasters,—the piers of masonry, the pilasters of iron.

Great arch. The great arch is composed of six ribs laid at equal distances and placed on strong abutment plates, firmly bedded in masonry. These are secured in their places by gauge-pipes and connecting wrought-iron bolts, covered with grated plates fastened by mortises fitted to joggles in the main ribs, and by screwed flanges. On these the spandril standard crosses are placed, and secured by gauge-pipes and cross ties in the middle, and tenons at top and bottom. On the top of these are the road bearers, one over each rib, and on them the road plates are secured.

Plate VI. Plate VI. Fig. 1 is an elevation of half the bridge.

Fig. 2 is a plan of one of the abutments.

Fig. 3 is a plan of the platform of the abutment.

Fig. 4 is a section through the abutment and one of the land arches.

Plate VII. Plate VII. Fig. 1 is an elevation of the main rib, shewing the spandril crosses and skirting, railing, &c.

Fig. 2 is a plate for connecting the main ribs.

Fig. 3 shews the mode of connecting the pieces of the main ribs together. The rib flanges are 4 inches deep.

Fig. 4 is a section of one of the spandril crosses, taken at the middle. They are connected by wrought-iron bolts, and kept apart by gauge-pipes.

Fig. 5 shews one of the main balusters.

Fig. 6 is a section of the hand-rail.

Fig. 7 shews the skirting.

Fig. 8 shews the road plates, $\frac{5}{8}$ inch thick, with flanges 3 inches high inside.

Fig. 9 is a section of the diagonal braces, $5\frac{1}{2}$ inches square in the middle, 4 inches at the ends.

Fig. 10 shews the manner of connecting the road bearers with the abutments. They are in four lengths on each side of the crown.

Fig. 11 gives a plan and section of the springing-plate.

Fig. 12 shews the form of the plates for connecting the top of the main ribs. Flanges stand up 3 inches inside.

Fig. 13 shews a cast-iron column.

The bridge erected on the Midland Counties Railway, over the Trent, near Sawley, is remarkable for its simplicity and the small number of its component parts.

Vol. iv. Professional Papers.

It consists of three arches of 100 feet span, 10 feet rise, and 30 feet width. The piers are of masonry up to the springing, with iron standards above.

There are six ribs laid at equal distances, with diagonal braces and distance-pieces between, bolted to fillets on the sides of the ribs. Each rib is cast in three pieces, comprehending the spandril standards and roadway bearers: a platform of half-baulks is laid on the bearers, with longitudinal pieces of oak for the rails. The iron standards are connected to the ribs by lap-joints with screw-bolts.

The piers are 14 feet thick at bottom and 10 feet at top.

The abutments are 12 feet thick, backed by a land arch springing from it, and the wing walls, which are about 3 feet 9 inches thick on an average, and extend 54 feet.

SECTION V. — DRAWBRIDGES, INCLUDING BASCULE, SWIVEL, ROLLER, AND OTHERS.

Object.

The object of every kind of drawbridge is to obtain a firm and secure means of communication across a river, canal, or ditch, with the means of cutting off that communication when necessary,—for the purpose usually, in the two former instances, of permitting the passage of vessels of too great size to go under,—and in the latter case, to prevent an enemy crossing the ditch and gaining an entrance into the place fortified.

They are generally of three kinds, viz. the Bascule, Balance or Lifting; the Turning or Swivel; and the Roller Bridge.

Bascule or Balance.

The Balance Bridge.—This is the old form of drawbridge, as found in most of the ancient castles and fortifications, in many of which it is simply a platform turning on a pivot or hinge in the escarp wall, and raised by means of chains attached to the end of the bridge and passing over pulleys above the entrance.

When across a canal or river, the bridge is usually composed of two leaves meeting in the middle when down, each of which turns vertically on a horizontal pivot fixed in the masonry or timber at the sides, a well-hole being sunk for the purpose of allowing the descent of the counterpoise attached to the tail of the bridge.

The following description is from the 1st volume of the 'Transactions of the Institution of Civil Engineers:'

Plate VIII. fig. 4.

"The bridge consists of eight cast-iron ribs, 9 inches deep at the centre or meeting by $1\frac{1}{2}$ inch thick in the plain part, and 2 or 3 at the edges, connected together by two sets of crosses to each leaf, the lowest close to the abutment, by hollow pipes and bolts nearer the middle, and by the meeting plates, which fit together with a tongue and groove. When the bridge is down, the under side or soffit of the ribs forms an arch of 36 feet 6 inches span and 3 feet 6 inches rise, resting on cast-iron abutment plates fixed in the masonry at the sides. From near the axis the ribs curve down below the fixed part of the bridge, and terminate in boxes of Kentlidge

by way of counterpoise, each box being attached to two ribs. The axis on which the bridge turns is 9 inches square, with five turned bearings working in plummer-blocks bedded in the stonework, the centre being 5 feet 3 inches from the side of the lock. The fixed part of the bridge is supported by iron joists resting on the division walls of the pits for the counterpoise.—The bridge is lifted by four crabs, two on each side; the handle is applied to a 6-inch pinion, working into a spur-wheel 4 feet diameter, having on its axis a 12-inch pinion, working into a toothed segment, 5 feet 9 inches radius, fixed to the outer ribs of the bridge." To render the bridge nearly on an equipoise in all positions, two chains are hooked on to the tail, and these, passing over two pulleys in the wall, are attached to a chain of heavy flexible links, hanging into the bridge-pit. "When the bridge is up, this chain tends by its weight to draw it down, and as the bridge descends, the chain falls on the bottom, forming a variable counterpoise. In raising the bridge, the reverse of this is the case. The bridge is about 100 tons in weight, and one leaf is usually opened or shut by three men in half a minute, but two *can* do it.—In comparing the balance with the swivel bridge, it may be observed that the former will work longer without adjustment, and bears more firmly on its abutments, but is more affected by the wind, costs more at the outset, and requires double the number of men to work it."

Swivel or Turning.

The swivel or turning bridge may also be formed in either one or two leaves. Each leaf turns horizontally on a pivot firmly fixed in the bank, on which it rests when open. Rollers are inserted beneath the end of the bridge, to make it move more freely.

The following is also from the 1st volume of the 'Transactions of the Institution of Civil Engineers:'

"Over this lock is a swivel bridge 12 feet 3 inches wide; it is 81 feet 9 inches long, and composed of two parts, which, meeting in the middle, form a segment of a circle. The bridge consists of six cast-iron ribs, about 2 inches thick in the plain part and $2\frac{1}{2}$ inches on the lower edge, connected together by cast-iron braces, and planked with $2\frac{1}{2}$-inch oak, covered with $1\frac{1}{2}$-inch fir. On each side of the lock, in the stone coping of a large brick pier, there is firmly imbedded a cast-iron circular plate, 11 feet 9 inches diameter by 6 inches wide, with a cross and pivot in the centre, also securely let into the masonry, and working in a socket under the bridge, with twenty conical rollers, 6 inches wide by $10\frac{3}{4}$ inches diameter, at one end, and $9\frac{3}{4}$ inches at the other, fitted in a frame, and revolving between the circular plate above mentioned and another similar one in the under side of the bridge. The ends or meeting parts of the bridge are not described from the centre pivot or axis of motion, but from a point on one side, whereby these parts, in shutting into a tongue and groove joint, do not come into actual contact till the bridge is shut, when it becomes completely fast, being wedged to the abutments on each side and kept in place by two keys at the meeting. The machinery consists of two 8-inch bevelled pinions, to one of which the handle is applied, and at the bottom of the vertical shaft of the other is fixed a 9-inch pinion, working into a spur-wheel, 4 feet diameter, on the axis of which is another pinion, 12 inches diameter, which turns the bridge by means of a toothed segment at the outer end. One man can open or shut either part of the bridge with ease in half a minute."

lication.

This kind of bridge is well adapted for positions where the abutments are low and there is a large horizontal space for working it. It does not appear to be well suited to the ditch of a fortification, for that reason.

ler Bridges.

Of the bridges now in use, the one which appears best adapted to its object is the roller bridge, as invented by Mr. Le Sueur, of Jersey. These bridges are withdrawn by means of a pinion working in a rack on the under side of the platform, with friction-rollers to render the work easier.

The following is from the 4th volume of Professional Papers:

Plate VIII. fig. 1. "This bridge cost £360. Plate VIII. fig. 1 shews a plan of the under side of the bridge; *a a* are oak beams 12 inches square; under these, iron rails, *b b*, are spiked, resting on rollers *g g* on the edge of the escarp; *c* is a rack bolted to the iron bearers *d d*, which also connect the whole framing; *e e* are trucks; and *f f* are friction-rollers, to ease the motion of the bridge. The hand-rail moves with the platform over rollers in the standards *p p*. When the bridge is withdrawn, the brow *x*, which moves on hinges, falls down over the opening in the escarp.

"Fig. 2 is a section through the ditch, and the bridge run out.

"Fig. 3 is an end view, shewing the working machinery.

"The width of the ditch is 17 feet 6 inches, and the entire length of the bridge 32 feet 9 inches; the inner part being 14 feet 6 inches, on the end of which 400 lbs. of scrap iron are bolted as a counterpoise, to prevent the outer part from sinking. The width of the bridge is 9 feet 2 inches clear, and it is covered with 3-inch oak plank.

Machinery. "In moving the bridge, the pinion *h* works in the rack *c*; the axis of this pinion is of 2½-inch iron, and is carried into one of the bomb-proofs, where it carries a toothed wheel acted on by another pinion to which the handle is attached.

"The force of one man on this handle is enough to move the bridge.

Advantages. Objections. "Its advantages are, that it does not obstruct the flanking fire of the place, and its withdrawal is entirely under command of men in the casemates. Its objections are, the length of time required to withdraw it, and the necessity for a level space in rear, the whole length of the bridge. The weight of the whole bridge is 6 tons 15 cwt. 3 qrs. 10 lbs. The whole might be advantageously made of cast iron."

Plate IX. fig. 1. There are two other kinds of drawbridges which have been adopted in Bermuda, as described in the 9th volume of Professional Papers. One of these is a balance bridge, in which, however, the outer end is lowered instead of being raised, as usual, to cut off the communication. When up, it is retained in its place by a long iron bolt, which would necessarily be subject to an immense strain during the passage of heavy weights, and consequently these bridges should only be used for foot passengers and other light traffic.

Figs. 2 and 3. The other kind of bridge is on the suspension principle, and invented by Colonel Blanshard. It is composed of several leaves jointed together, and is supported by two chains on each side, passing through the suspending pieces, to which the leaves are attached. The upper chain on each side is fastened to the ground, 12 feet from the counterscarp, passes over a pillar 2 feet high and 1 foot from the edge of the counterscarp, and after crossing the ditch, is carried over a 6-inch sheave on the side of the opening in the escarp, on a level with the top of the counterscarp pillar, and thence round a windlass beneath the roadway, and 23 feet from the face of the escarp. The lower chain is fastened to a hook in the face of the counterscarp, and, crossing the ditch, passes over a sheave below the other, and round a windlass placed 20 feet from the escarp.

In the 3rd volume of Professional Papers, page 189, Colonel Jebb has given a description of a drawbridge particularly applicable when it is necessary that the platform should be withdrawn to one side instead of along the straight line.

SECTION VI.—SUSPENSION BRIDGES.

Various opinions have been entertained as to the form best adapted for the objects of a suspension bridge. These objects are,—1st. The obtaining a roadway across a river in a position where it is necessary to allow the passage of vessels beneath it,

and where it is not possible to form piers or abutments sufficiently close together to allow of an ordinary arch being constructed. 2ndly. The judicious arrangement of the suspending chains, rods, and roadway bearers, to effect the greatest firmness and rigidity with the least expenditure of material.

The question does not yet appear to be fully settled, but the preference, in theory at least, seems to be given to Dredge's Taper Chain. The following are the heads under which the different forms may be arranged.

Professional Papers, vol. ix.

First. Those in which the planking of the roadway (except a small portion near the abutments) rests solely on the main suspending chains, as in Chinese bridges generally, and some in South America.

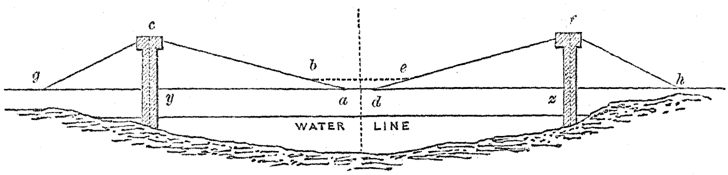
Second. Those in which the roadway side beams, carrying the planking, railing, &c., are only connected with the main suspending chains by vertical rods, as in the Menai Bridge, and numerous others.

Third. Those in which the roadway platform is entirely supported by ropes, chains, or wires proceeding obliquely from the top of the abutments, as in some bridges of rope, canes, or bamboos, in Asia, and light wire bridges in Europe. (A light rope bridge of this description may be seen in Plate XIV. under the head of 'Field Bridges,' in vol. i.)

Fourth. Those in which the roadway platform is partly supported by ropes or chains, or wires proceeding obliquely from the top of the abutments, partly by rods descending obliquely from the main chains, and partly by the main suspending chains themselves; which last, diminishing in weight as they approach the middle of the span, are linked to the central portion of the roadway by short rods, which, being nearly in continuation of the upper parts of the main chains, would, if strong enough, support that part of the roadway, and complete the curve, rendering the central link of the chain nearly unnecessary, as in Dredge's Bridge.

I propose first to consider the fourth case. In this it is necessary that the central portion of the roadway bearers should be made strong in proportion as the centre link *b e* (see annexed figure) of the main chain is weakened.

Fig. 6.



In all suspension bridges, chains are carried from the top of the abutments to the rear, and called back chains. There is one of these to each of the bridge chains, whether they carry the rods on each side, as in those of the second class, or go directly to the platform, as in the third and fourth classes. These back chains are connected with links secured on the top of cast-iron saddles on the abutments at one end, and firmly bolted to strong girders or blocks of masonry in the solid ground at the other.

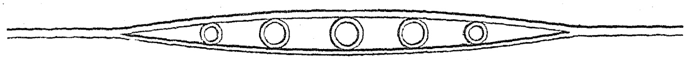
Professional Papers.

In the case before us, the tension on the centre link will increase in an inverse ratio to the deflection of the chain. When *b a* becomes vertical, there is no tension on the roadway *a d*, but all on the link *b e*, and the tension on that portion of roadway will be greatest when the angle *b a y* is least; *i. e.* when *b a*, and *a d*, both become parts of the suspending chain. In this latter case strong holdfasts are necessary to prevent the roadway bending and the ends of the side-beams flying out from the abutments.

It seems best, however, to give the centre link sufficient strength to support the roadway in case of fracture of the side beams, which should also be made of great strength in the centre, to give rigidity to the structure.

For this purpose I would suggest, that instead of adding breadth to the side roadway bearers, as proposed by Major Goodwyn in the Ballee Khâl Bridge, it would be far better to give them additional depth, like the annexed figure, and to increase the lateral strength of the platform by means of diagonal braces between the bearers.

Fig. 7.

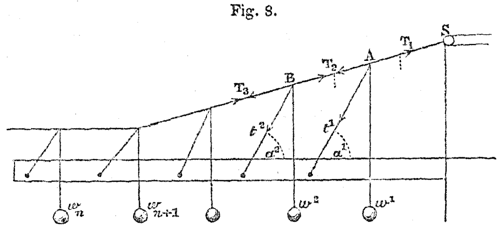


The form of bridge described under the third head, having the road bearers entirely supported by chains descending from the piers without any rods, would be very good, but for the difficulty of equalizing the tension in large spans. It is, however, well to have two or three besides the main chains descending from the piers direct, the chief objection to Dredge's Bridge being, that he carries the principle of tapering the chains too far, without rendering his side bearers strong enough to compensate.

Professional Papers.

The following formulæ are applicable to all cases of suspension bridges; the middle link being supposed horizontal, and the number of links $2n + 1$.

Fig. 8.



In the above figure, let $w_1\ w_2 \ldots\ldots w_{n+1}$ be the weights of the links from either pier to the centre; $S_1\ S_2 \ldots\ldots S_w$ the weights of the suspending rods; $T_1\ T_2 \ldots\ldots T_{n+1}$ the tensions of the links, and $t_1\ t_2 \ldots\ldots t_n$ the suspending rods.

The two forces T_1 and T_1 support the weight of roadway links and rods, $= w$. Then $T_1 = \frac{1}{4} w \cdot \operatorname{cosec} \beta_1$.

Also,

$$T_2 = \frac{\sin(\alpha_1 - \beta_1)}{\sin(\beta_1 - \beta_2)} t_1 + \tfrac{1}{2}(w_1 + w_2 + S_1) \cdot \frac{\cos \beta_1}{\sin(\beta_1 - \beta_2)}$$

$$T_{n+1} = \frac{\sin(\alpha_n - \beta_n)}{\sin(\beta_n - \beta_{n+1})} t_n + \tfrac{1}{2}(w_n + w_{n+1} + S_n) \cdot \frac{\cos \beta_n}{\sin(\beta_n - \beta_{n+1})}$$

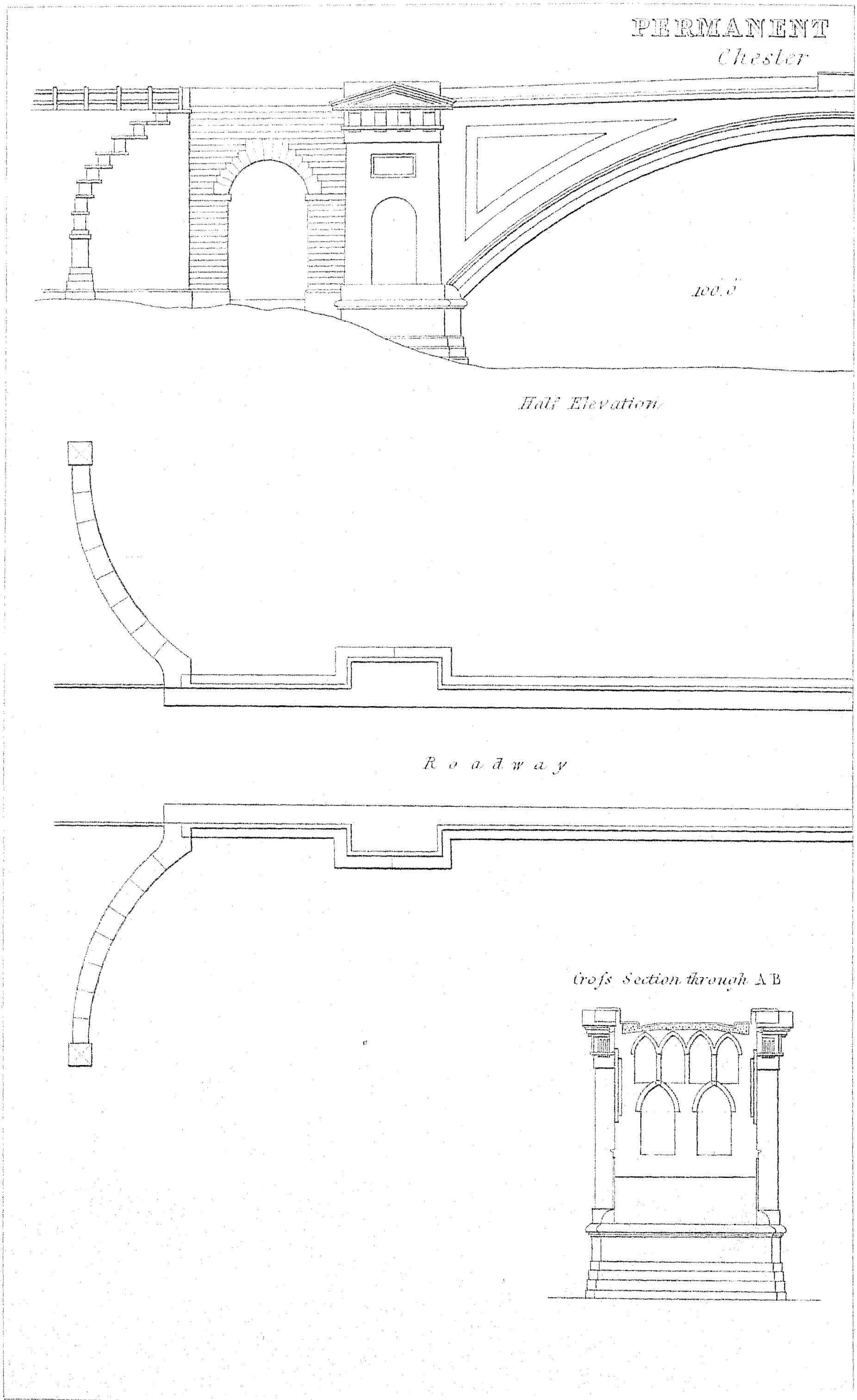
for the tensions of the links.

The following are the tensions of the suspending rods:

$$t_1 = \frac{\sin(\beta_1 - \beta_2)}{\sin(\alpha_1 - \beta_2)} T_1 - \tfrac{1}{2}(w_1 + w_2 + S_1) \cdot \frac{\cos \beta_2}{\sin(\alpha_1 - \beta_2)}$$

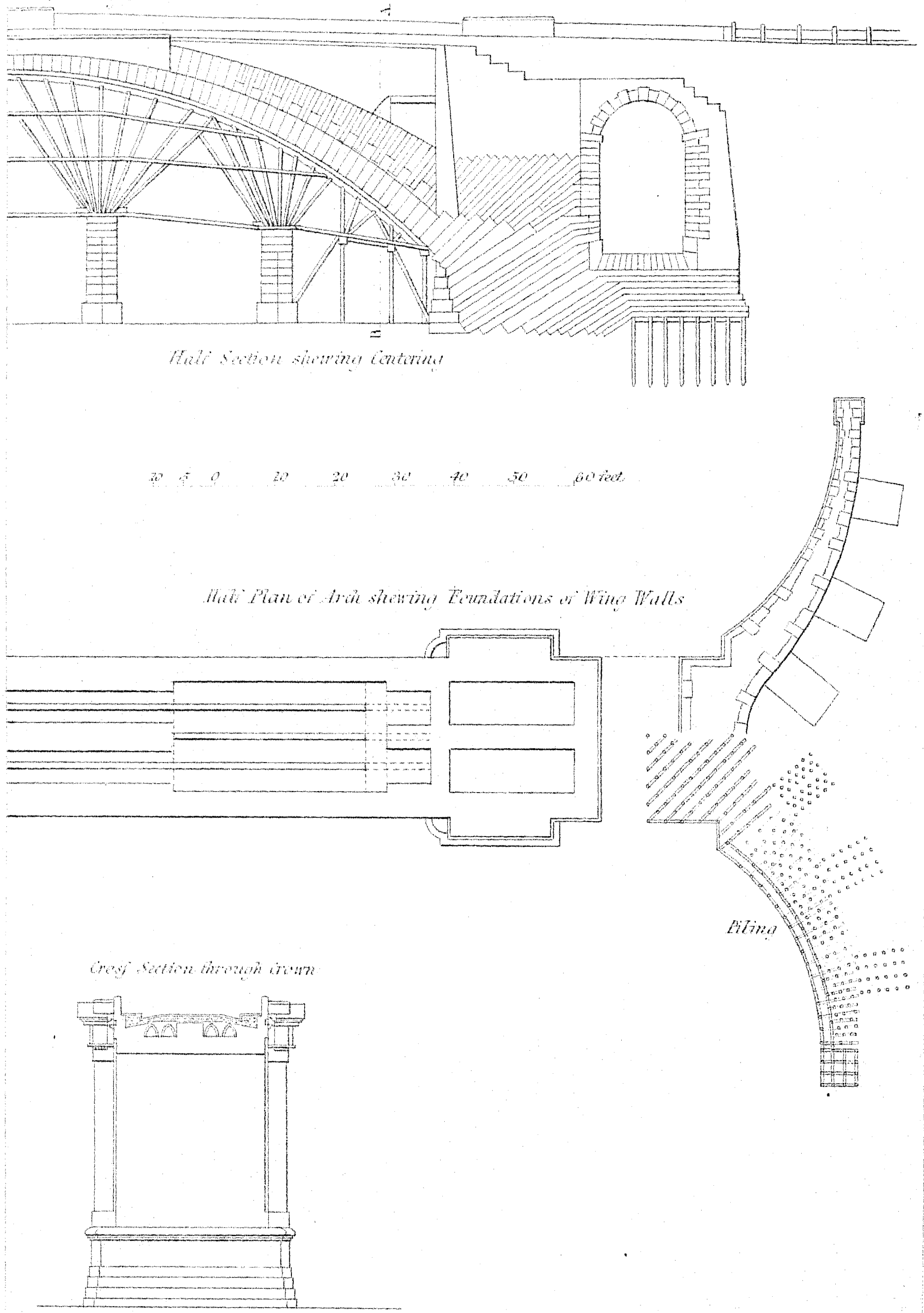
$$t^2 = \frac{\sin(\beta_2 - \beta_3)}{\sin(\beta_1 - \beta_2)} \cdot \frac{\sin(\alpha_1 - \beta_1)}{\sin(\alpha_2 - \beta_3)} \left\{ t_1 + \tfrac{1}{2}(w_1 + w_2 + S_1) \cdot \frac{\cos \beta_1}{\sin(\alpha_1 - \beta_1)} \right\} - \tfrac{1}{2}(w_2 + w_3 + S_2) \frac{\cos \beta_3}{\sin(\alpha_2 - \beta_3)}$$

$$t_n = \frac{\sin(\beta_n - \beta_{n+1})}{\sin(\beta_{n+1} - \beta_n)} \cdot \frac{\sin(\alpha_{n-1} - \beta_{n-1})}{\sin(\alpha_n - \beta_{n+1})} \left\{ t_{n-1} + \tfrac{1}{2}(w_{n-1} + w_n + S_{n-1}) \right.$$


PERMANENT
Chester
Half Elevation
Roadway
Cross Section through AB

BRIDGES

Bridge.



PERMANENT BRIDGES.

Fig. 1.

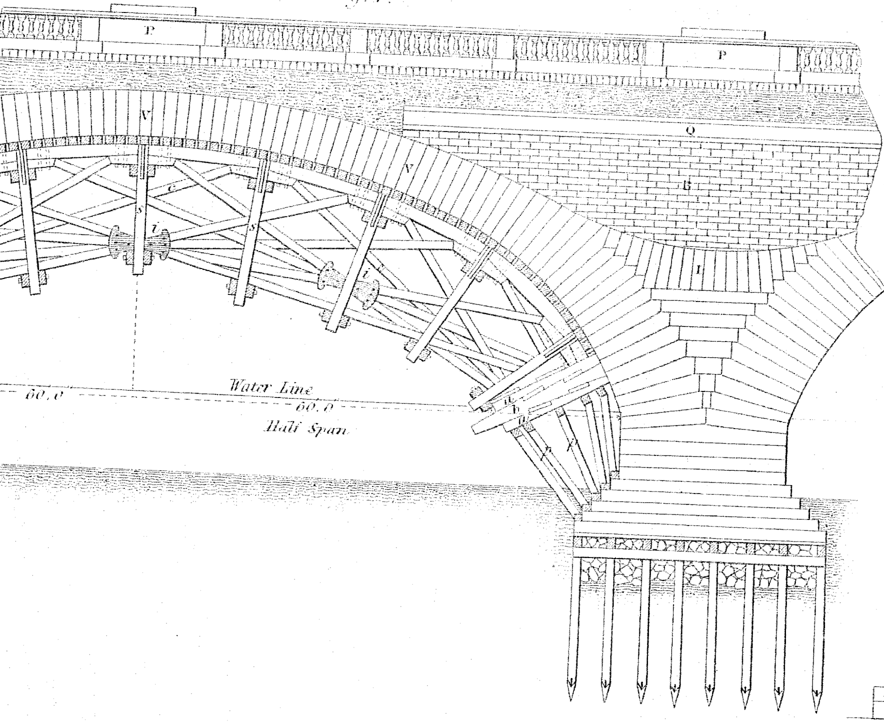


Fig. 2.

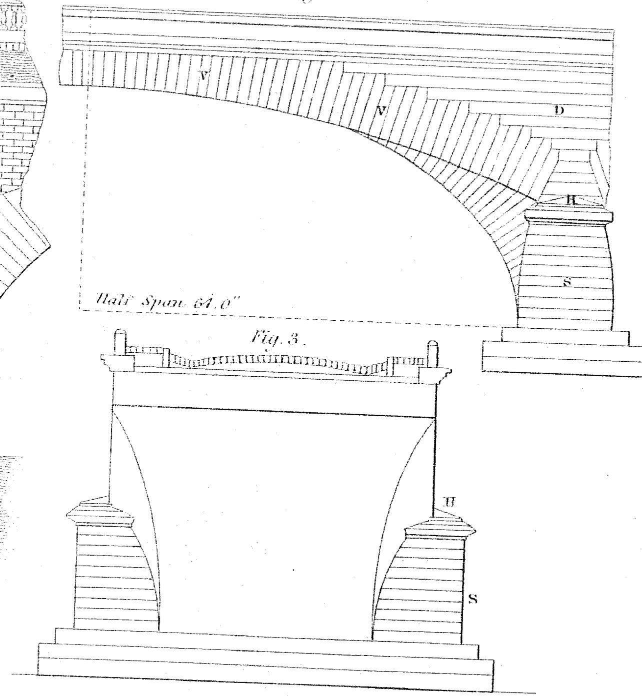
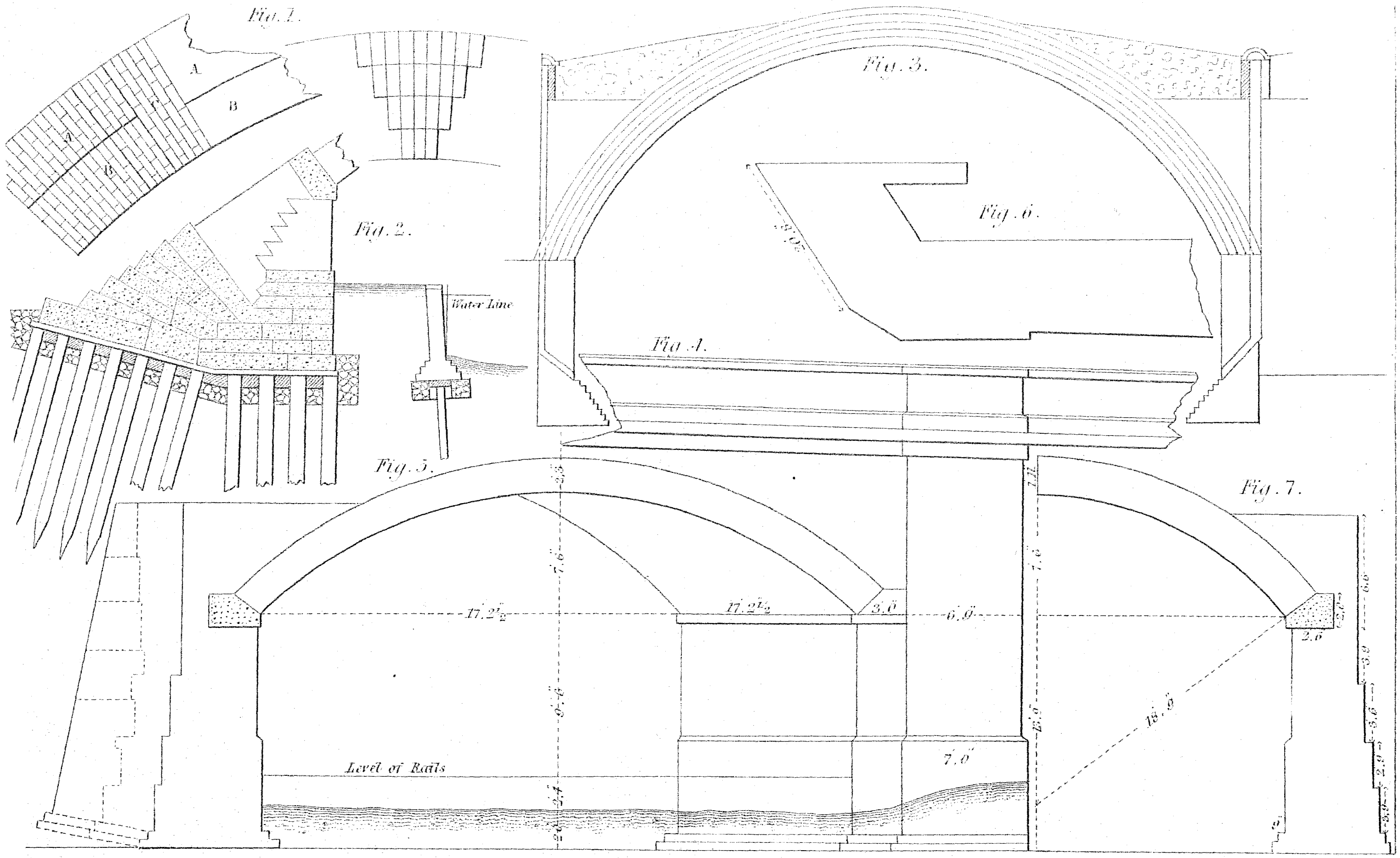
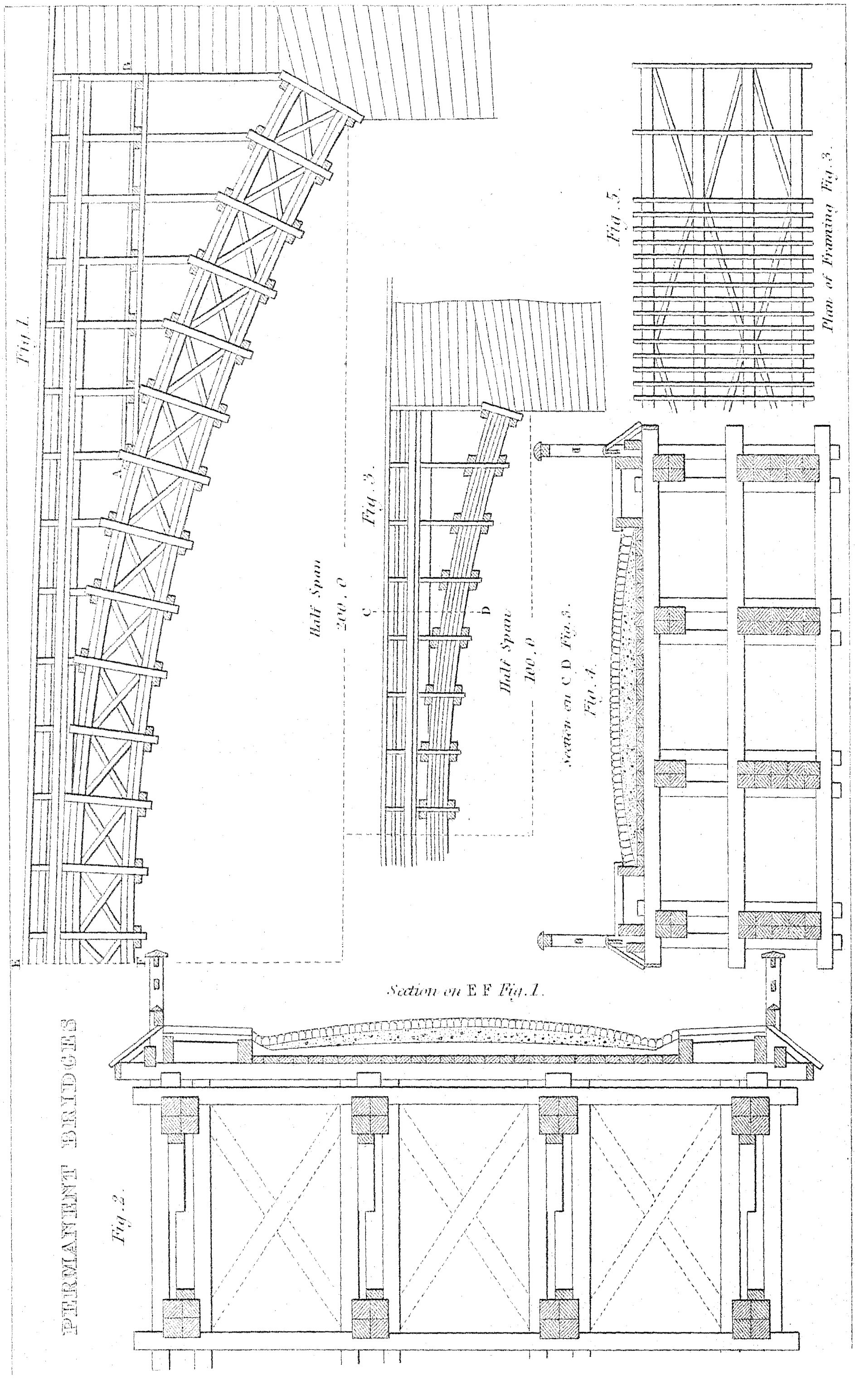
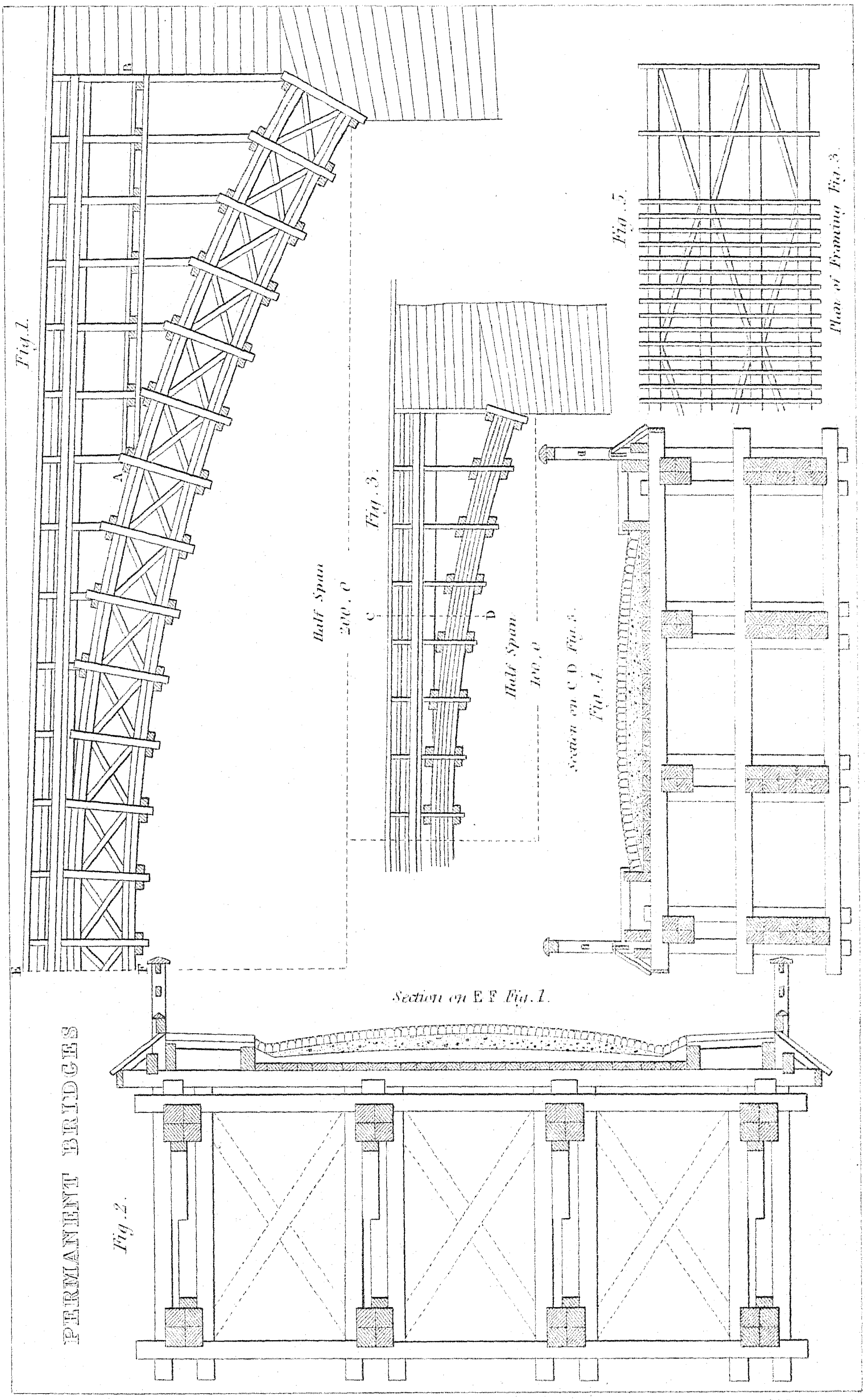


Fig. 3.

PERMANENT BRIDGES.



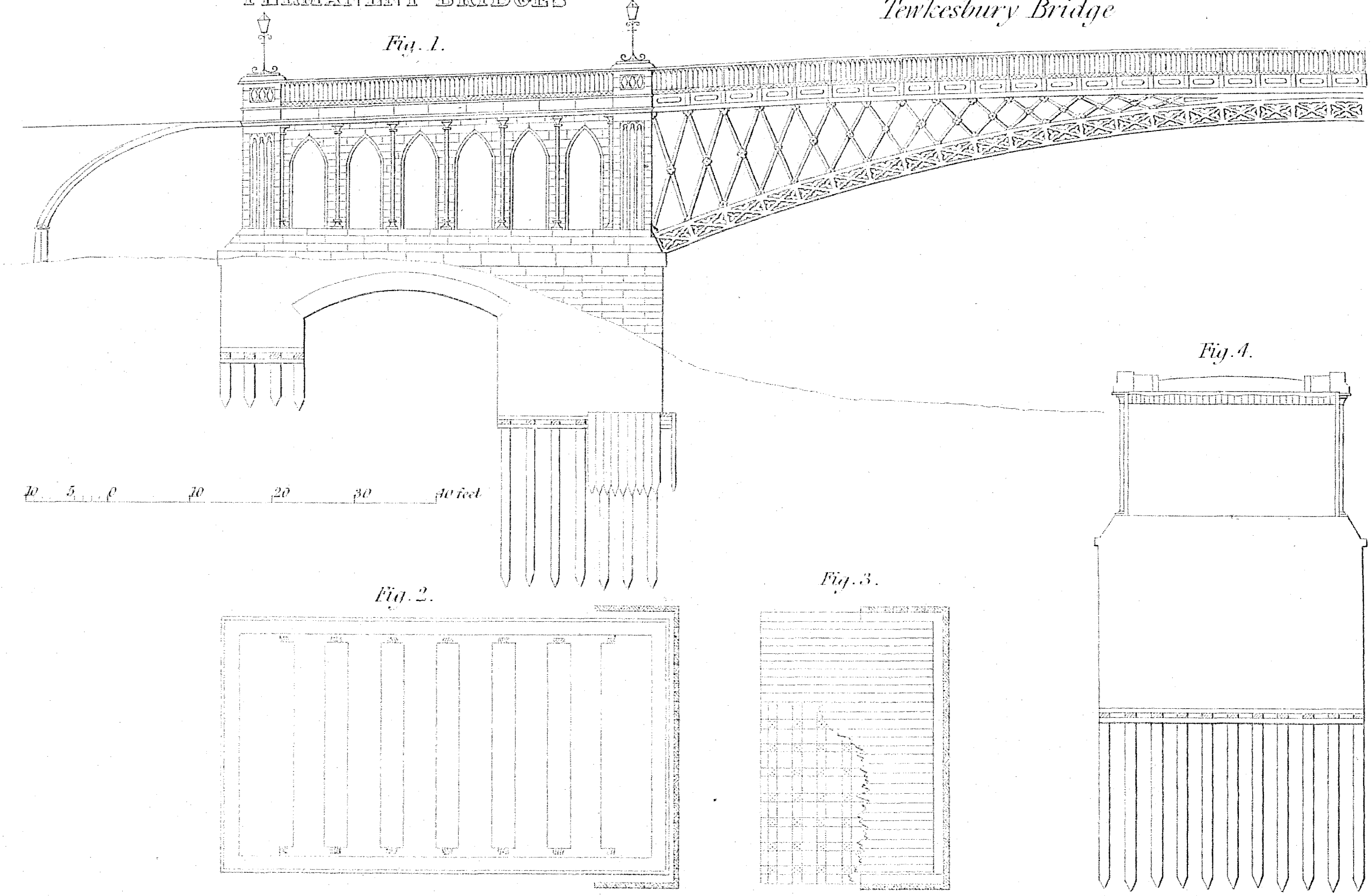

PERMANENT BRIDGES
Fig. 1.
Half Span
200, 0
Fig. 2.
Section on E F Fig. 1.
Fig. 3.
Half Span
100, 0
Section on C D Fig. 3.
Fig. 4.
Fig. 5.
Plan of Framing Fig. 3.



L.R.Binney del.

PERMANENT BRIDGES

Tewkesbury Bridge



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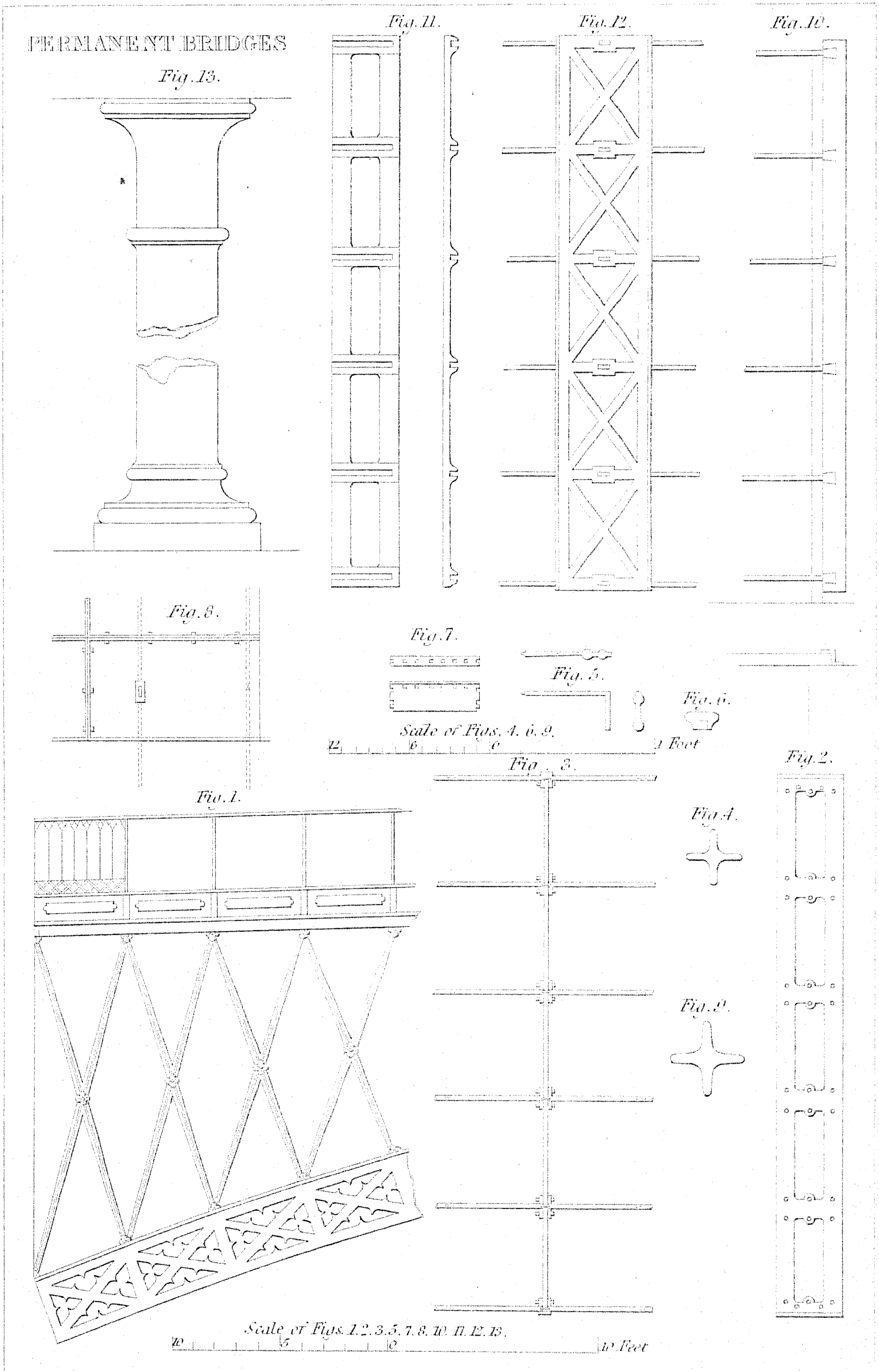
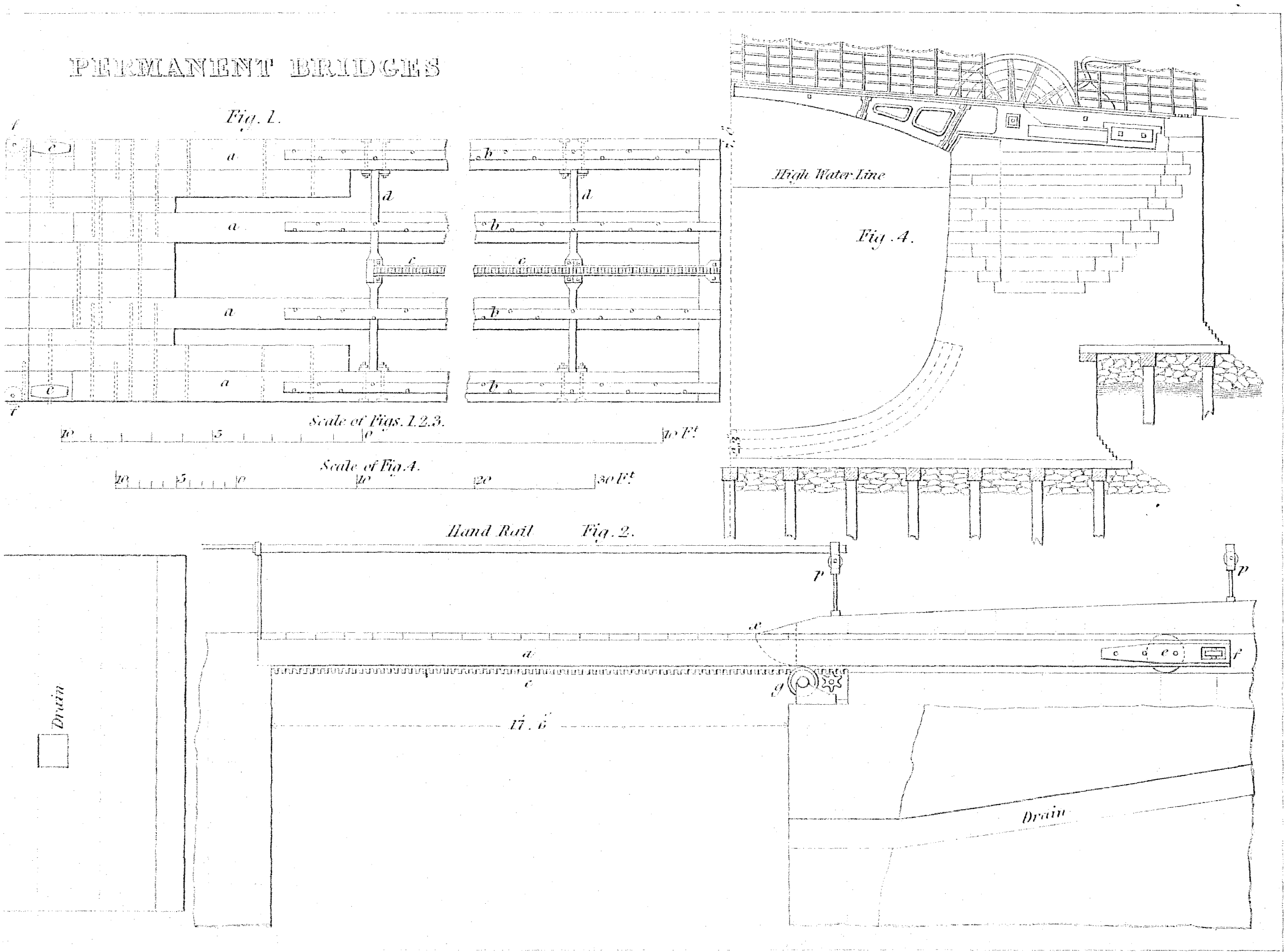
J. W. Lowry fc.


PERMANENT BRIDGES
Fig. 13.
Fig. 11.
Fig. 12.
Fig. 10.
Fig. 8.
Fig. 7.
Fig. 5.
Fig. 6.
Scale of Figs. 4. 6. 9.
12 6 0 1 Foot
Fig. 3.
Fig. 2.
Fig. 1.
Fig. 4.
Fig. 9.
Scale of Figs. 1. 2. 3. 5. 7. 8. 10. 11. 12. 13.
10 5 0 10 Feet

PERMANENT BRIDGES



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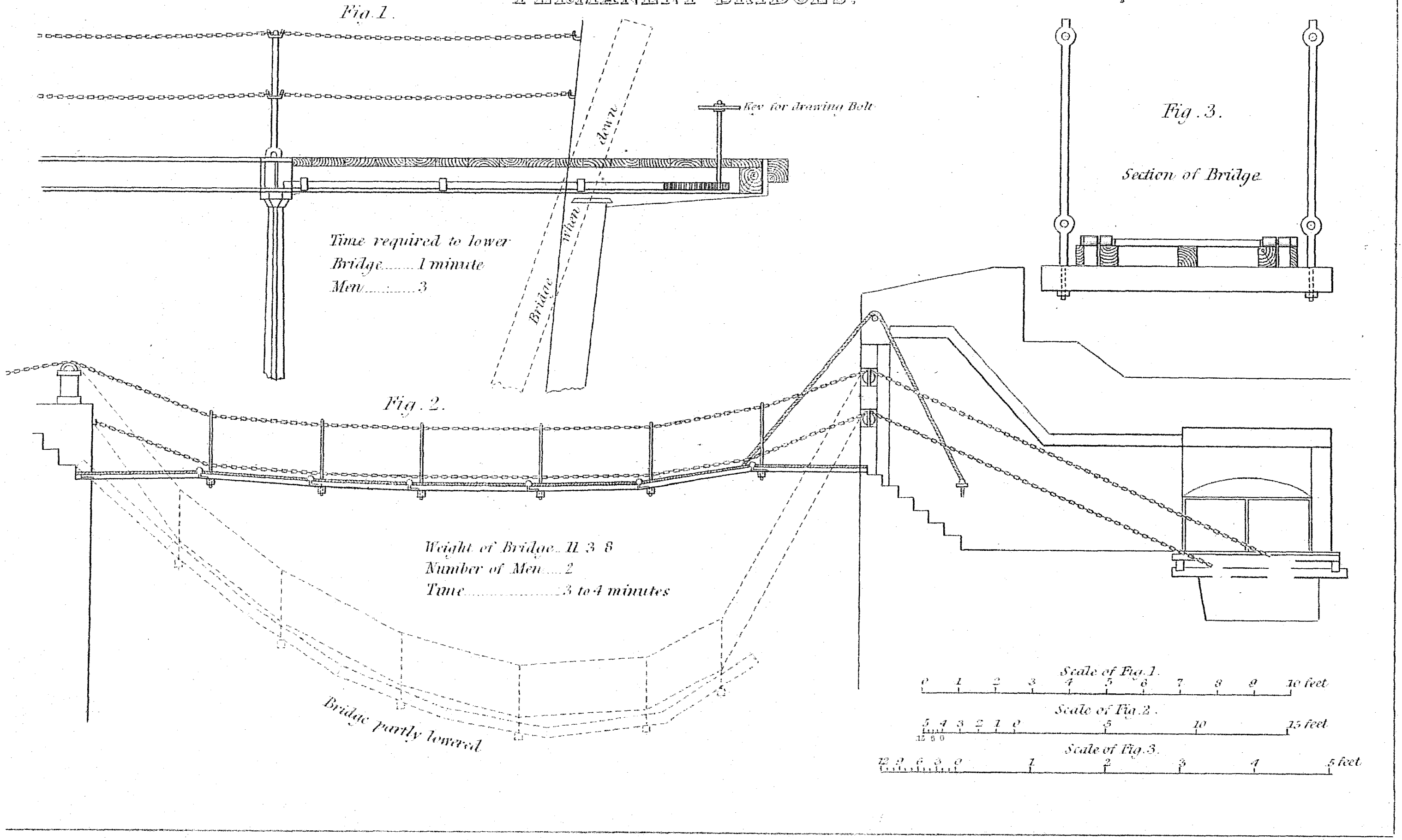

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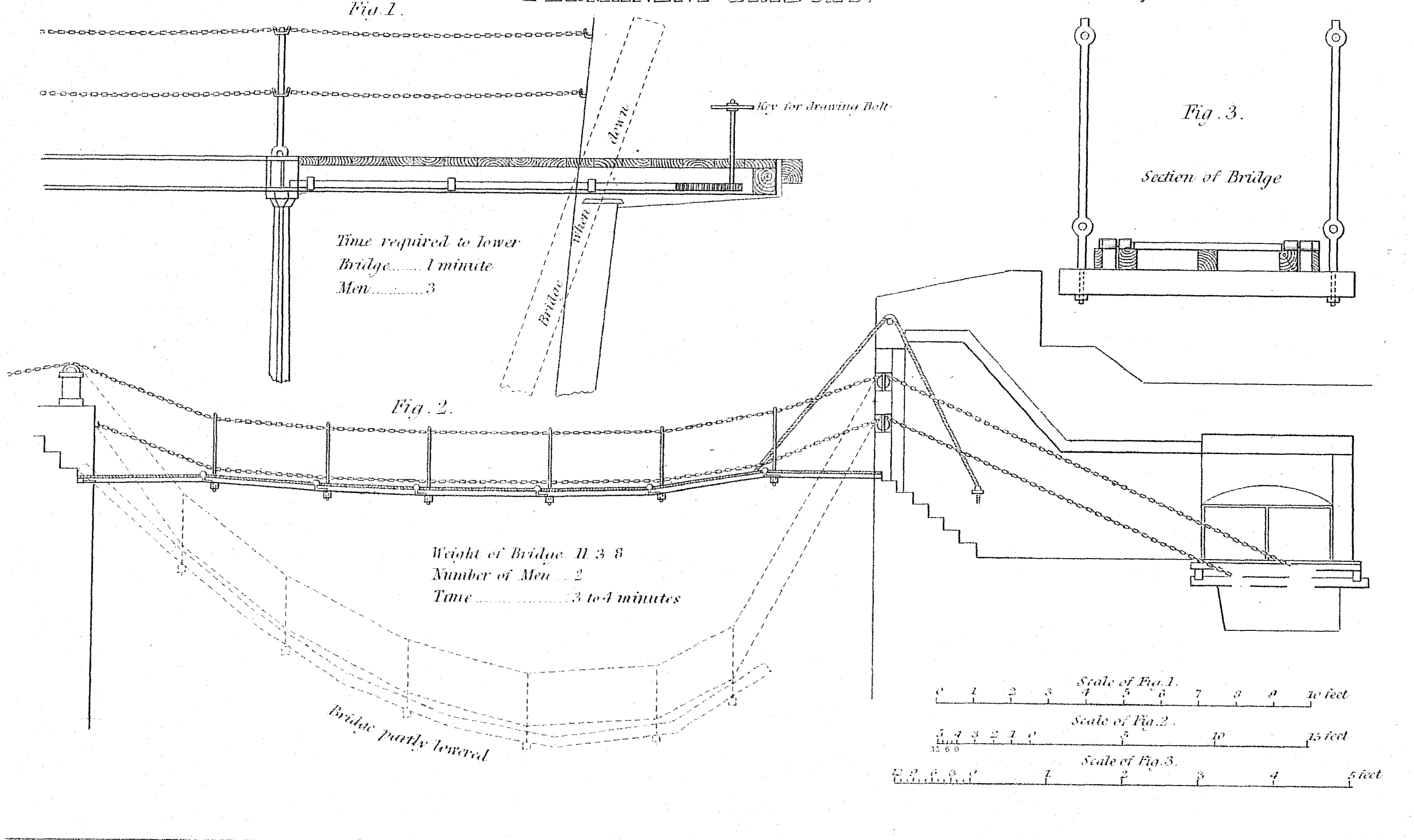
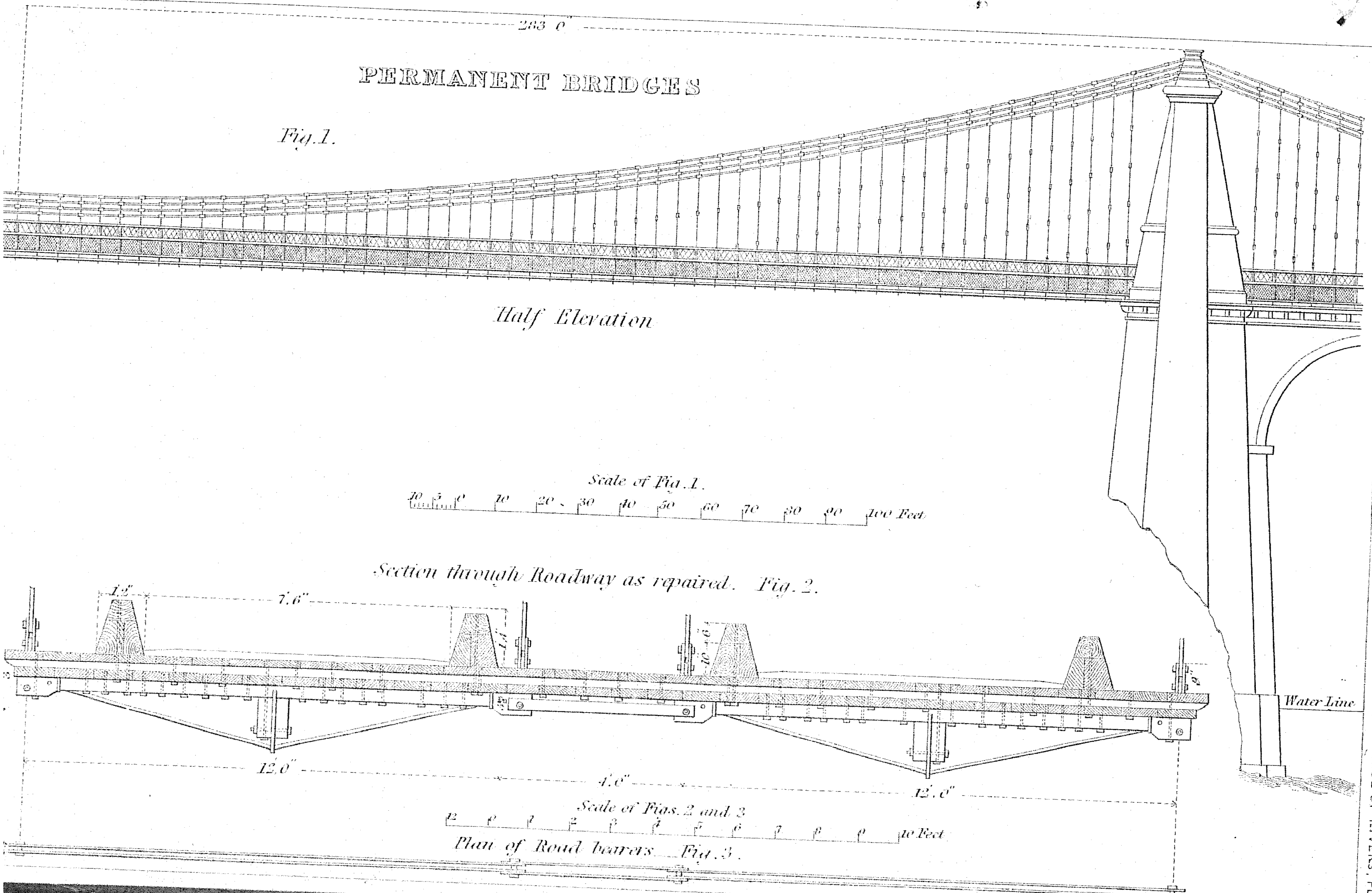


PERMANENT BRIDGES



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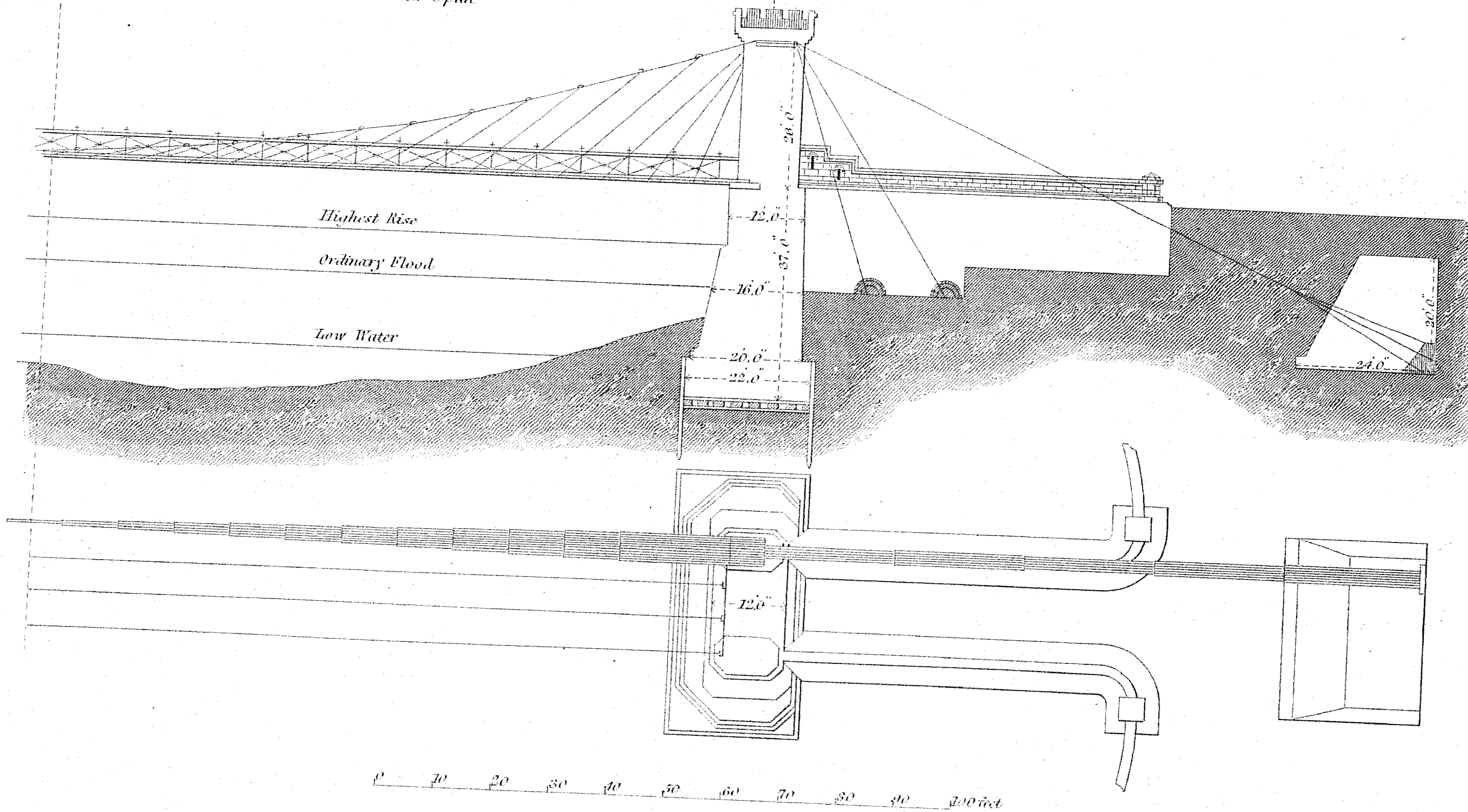


L. R. Binney del.

Plate X.
Menai Brid

Plate XI.

$$\left.\frac{\cos\beta_{n-1}}{\sin(\alpha_{n-1}-\beta_{n-1})}\right\} - \tfrac{1}{2}\,(w_n + w_{n+1} + S_n)\cdot\frac{\cos\beta_{n+1}}{\sin(\alpha_n - \beta_{n+1})} \qquad (\beta_{n+1} = 0)$$

Plate X. represents the bridge erected by Telford over the Menai Straits. In this there are four chains on each side, one above the other, and the same number in two lines along the middle, the pathway being between. The rods are connected alternately to the first and third, and the second and fourth chains. They are placed 5 feet apart, and the centre span of the centre arch is, I think, 566 feet. Some years ago the violent action of a storm destroyed part of the roadway, but did not injure the chains. In this bridge the back chains support half-bays of the bridge.

Fig. 1 is an elevation of half the bridge.

Fig. 2 is a transverse section of the roadway, after the alterations executed by Mr. Provis, in consequence of the damage done by a severe storm in 1839. An additional row of planks was placed on the platform, and the footpaths were disconnected from the roadways, in order that, since thorough stiffness could not be given to a bridge in so exposed a position, the undulations occasioned by the wind might not cause the transverse bearers to break; and for the same reason an additional joint was formed in the suspension rods, just above the roadway. It is considered by some, that it is a great advantage to have a strongly trussed side railing to suspension bridges, to increase their stiffness longitudinally. The section of the chains gives 260 square inches of iron.

Plate XI. represents the bridge erected by Major Goodwyn over the Ballee Khâl, near Calcutta, on a modification of the principles adopted by Mr. Dredge, the chains not being so much tapered, and the roadway being strengthened.

Fig. 1 is an elevation and section, shewing the mode of securing the back chains.

Fig. 2 is a plan of the chains and abutment.

PENDULUM * [Latinè pendulum (*scil.* negotium), that which hangs down, dangles, from pendeo, I hang,] in Mechanics denotes any body so suspended that it is at liberty to vibrate or swing backwards and forwards, about a horizontal axis of suspension, by the action of gravity.

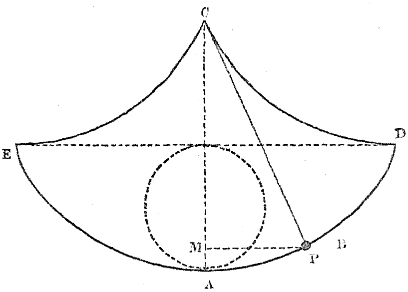
Pendulums receive particular denominations according to the mode of their construction, or the purpose which they are intended to serve.

The *simple* pendulum is a mere theoretical abstraction, in which, for the purpose of more readily demonstrating the properties of this important machine, it is assumed that the whole weight of the suspended body is concentrated in a single point; that the cord by which it is suspended is without weight, of invariable length, and perfectly free from rigidity; that there is no friction at the axis of suspension, and no resistance to motion opposed by the atmosphere.

Properties of simple pendulums vibrating in cycloidal arcs.

It is a known property of the cycloid, that its evolute is a cycloid similar and equal to the former. If, then, a simple pendulum be suspended from C, the point of concurrence of two equal inverted semi-cycloidal cheeks, by a string of the proper length, and be made to vibrate between them, the heavy point P of the pendulum will describe an arc of an equal and similar cycloid D A E. The proper length of the suspending cord is twice the diameter of the generating circle. P then representing the position

* By Mr. Heather, Royal Military Academy, Woolwich.



of the heavy point at any time t, let $AM = x$, $MP = y$, $AP = s$, the radius of the generating circle $= a$, and the length of the suspending cord $= l$; then by the property of the curve $s = 2\sqrt{2ax}$; and therefore $s^2 = 8ax = 2lx$, since $l = 4a$. But, if ϕ be the angle which the tangent at P makes with the vertical, $\cos\phi = \frac{dx}{ds} = \frac{s}{l}$, and the force accelerating the body's motion in the direction of the curve is $g\cos\phi = \frac{g}{l}s$. The equation of motion therefore is $\frac{d^2 s}{dt^2} + \frac{g}{l}s = 0$, whence it appears that $s = A\cos(t\sqrt{\frac{g}{l}} + C)$, and $\frac{ds}{dt} = -A\sqrt{\frac{g}{l}}\sin(t\sqrt{\frac{g}{l}} + C)$, A and C being constants depending upon the given conditions of the problem. Let, for instance, the length of the arc from the lowest point A to the point B, from which the heavy point begins to descend, $= s_1$, and let the time be reckoned from the moment when a descent commences; then, when $t = 0$, $s = s_1$, and $\frac{ds}{dt} = v = 0$; and, substituting these values in the above equations, it appears that $s = A\cos C$, and $0 = -A\sqrt{\frac{g}{l}}\sin C$; and hence $C = 0$, and $A = s_1$, and therefore

$$s = s_1\cos t\sqrt{\frac{g}{l}}, \text{ and } v = -\frac{ds}{dt} = s_1\sqrt{\frac{g}{l}}\sin t\sqrt{\frac{g}{l}}.$$

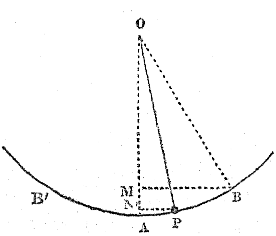
When the heavy point P arrives at A, $s = 0$, and therefore

$$\cos t\sqrt{\frac{g}{l}} = 0, \text{ and } t\sqrt{\frac{g}{l}} = \frac{\pi}{2}, \text{ or } \frac{3\pi}{2}, \text{ or } \frac{5\pi}{2}, \text{ or \&c.}$$

Hence the time of a semi-vibration, or time in which the heavy point first arrives at the lowest point A, is $\frac{\pi}{2}\sqrt{\frac{l}{g}}$, and the time of each complete vibration is $\pi\sqrt{\frac{l}{g}}$.

It appears, then,—1. That the time of vibration in a cycloidal arc is the same, whatever be the extent of the arc of vibration; 2. That the time of vibration is directly proportional to the square root of the length of the pendulum; and 3. That the time of vibration is inversely proportional to the square root of the force of gravity.

Properties of simple pendulums vibrating in circular arcs.



Let the heavy point P be suspended from an axis at O, and vibrate in the circular arc B A B′, of which O A, the length of the pendulum, is the radius; and let B be the point from which the descent commences, A the lowest point of the arc, and P the position of the heavy point at any time t. Through B and P draw the horizontal lines B M and P N to meet the vertical line O A in the points M and N; and let $AM = h$, $AN = x$, $AP = s$, and $OA = l$. Then v, the velocity at the point P, = the velocity

acquired in falling through the height $MN = \sqrt{2g.MN} = \sqrt{2g(h-x)}$;

and, since s decreases as t increases, $v = -\frac{ds}{dt}$, and $\frac{dt}{ds} = -\frac{1}{\sqrt{2g(h-x)}}$; but

$\frac{ds}{dx} = \frac{l}{\sqrt{2lx - x^2}}$, and therefore $\frac{dt}{dx} = \frac{dt}{ds}\cdot\frac{ds}{dx} = -\frac{l}{\sqrt{2g(h-x)(2lx-x^2)}}$.

We are not able to integrate this expression in a finite form; but it can be expanded into a series of which the terms can be separately integrated, and in this manner the integral can be obtained to any required degree of approximation. Thus—

$$\frac{dt}{dx} = -\tfrac{1}{2}\sqrt{\frac{l}{g}}\,\frac{1}{\sqrt{hx-x^2}}\left(1-\frac{x}{2l}\right)^{-\frac{1}{2}} =$$

$$-\tfrac{1}{2}\sqrt{\frac{l}{g}}\,\frac{1}{\sqrt{hx-x^2}}\left\{1+\frac{1}{2}\,\frac{x}{2l}+\frac{1.3}{2.4}\left(\frac{x}{2l}\right)^2+\ldots+\frac{1.3\ldots(2n-1)}{2.4\ldots 2n}\left(\frac{x}{2l}\right)^n+\ldots\right\}.$$

$$\text{Now} \int_h^o \frac{x^n\,dx}{\sqrt{hx-x^2}} = \frac{2n-1}{2n}\,h\int_h^o \frac{x^{n-1}\,dx}{\sqrt{hx-x^2}}, \text{ and} \int_h^o \frac{dx}{\sqrt{hx-x^2}} = -\pi;$$

$$\text{therefore} \int_h^o \frac{x\,dx}{\sqrt{hx-x^2}} = -\frac{1}{2}\pi h, \int^o \frac{x^2\,dx}{\sqrt{hx-x^2}} = -\frac{1.3}{2.4}\pi h^2, \text{ and so on;}$$

but between the limits $x = h$ and $x = 0$, t is the time of a semi-vibration, and therefore the time of a semi-vibration is

$$\frac{\pi}{2}\sqrt{\frac{l}{g}}\cdot\left\{1+\frac{1^2}{2^2}\,\frac{h}{2l}+\frac{1^2.3^2}{2^2.4^2}\left(\frac{h}{2l}\right)^2+\ldots+\frac{1^2.3^2\ldots(2n-1)^2}{2^2.4^2\ldots(2n)^2}\left(\frac{h}{2l}\right)^n+\ldots\right\}.$$

When the arc of vibration is very small, the second and all the succeeding terms of this series are so exceedingly small that they may ordinarily be neglected, and the time of a complete vibration represented by $\pi\sqrt{\frac{l}{g}}$, which coincides with that in a cycloid.

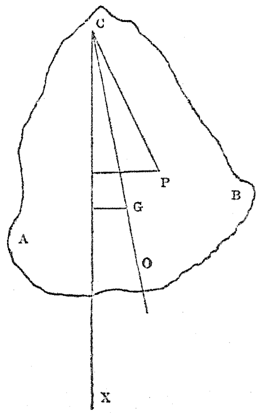
The second term of the series gives a correction to be added to the time of a vibration, $= \pi\sqrt{\frac{l}{g}}\,\frac{h}{8l}$, or $= \pi\sqrt{\frac{l}{g}} \times \cdot 000019038\, d^2$, if d be the number of degrees in A B, half the arc of vibration.

If the time of vibration of a pendulum in a cycloidal, or infinitely small circular arc, be 1″, so that $\pi\sqrt{\frac{l}{g}} = 1$, the increment of the time for the circular arc $2d$ will be $\cdot 000019038\, d^2$, and the time lost in a day will be $24 \times 60 \times 60 \times \cdot 000019038\, d^2 = \frac{5}{3}d^2$, nearly. Thus if the arc of vibration be 4°, the time lost in a day will be $6''\frac{2}{3}$, nearly; if the arc be 2°, the time lost in a day will be $1''\frac{2}{3}$; if the arc be 1°, the time lost in a day will be $\frac{5}{12}''$; and if the arc be but $\frac{1}{2}$°, the time lost in a day will be but $\frac{5}{48}''$ only.

Connection between the simple pendulum and any body vibrating about a horizontal axis, and acted upon by gravity only.

Let A B C be a vertical section of the body made by the plane of the paper passing

through the centre of gravity G, and cutting the axis of suspension perpendicularly in C; let P, P′, P″, &c. be the projections upon this plane of the particles m, m', m'', &c., and Cx a vertical line through C; and let C$g = h$, the radius of gyration about an axis through the centre of gravity $= k$, C P $= r$, C P′ $= r'$, C P″ $= r''$, &c., G C $x = \theta$, and P C $x = \phi$, P′ C $x = \phi'$, P″ C $x = \phi''$, &c. The forces impressed on the particles m, m', m'', &c. are respectively $m\,g$, $m'\,g$, $m''\,g$, &c., and the moments of these forces about the axis of suspension are $m\,g\,r \sin\phi$, $m'\,g\,r' \sin\phi'$, $m''\,g\,r'' \sin\phi''$, &c. Therefore



$$\frac{d^2\theta}{d\,t^2} = -\frac{\text{moment of impressed forces}}{\text{moment of inertia}}$$

$$= -\frac{g\,\{m\,r \sin\phi + m'\,r' \sin\phi' + m''\,r'' \sin\phi'' + \text{\&c.}\}}{m\,r^2 + m'\,r'^2 + m''\,r''^2}$$

$$= -\frac{\mathrm{M}\,g\,h \sin\theta}{\mathrm{M}\,(h^2 + k^2)},$$

if M represent the sum $m + m' + m''$ + &c., or the entire mass of the body. Hence

$$\frac{d^2\,\theta}{d\,t^2} = -g\,\frac{h}{h^2 + k^2} \sin\theta.$$

In C G produced take C O $= \dfrac{h^2 + k^2}{h}$; then if the whole mass M were collected at O, and connected with the axis of suspension at C by a cord without weight, the moment of the impressed force would be M g . C O sin θ, while the moment of inertia would be M . C O², and therefore we should have

$$\frac{d^2\,\theta}{d\,t_2} = -\frac{\mathrm{M}\,g\;\mathrm{C\,O} \sin\theta}{\mathrm{M}\,.\,\mathrm{C\,O}^2} = -\frac{g \sin\theta}{\mathrm{C\,O}} = -g\,\frac{h}{h^2 + k^2} \sin\theta,$$

the same equation for determining the motion as before. Hence it appears that the time of vibration of the body A B C is the same as that of a simple pendulum whose length $l = \mathrm{C\,O} = \dfrac{h^2 + k^2}{h}$, and, in fact, that all the circumstances of the motion of the point O are the same as if it were the heavy point of such simple pendulum.

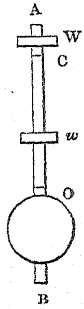
The point O is called the centre of oscillation; the point C, the centre of suspension; the vibrating body, a compound pendulum; and $l = \dfrac{h^2 + k^2}{h}$, the length of the corresponding simple pendulum.

Since $l = h + \dfrac{k^2}{h}$, and hence $l - h = \dfrac{k^2}{h}$, and $h = \dfrac{k^2}{l - h}$, if the body be suspended anew on an axis through O parallel to that through C, and l' represent in this case the length of the equivalent simple pendulum, then

$$l' = \mathrm{O\,G} + \frac{k^2}{\mathrm{O\,G}} = l - h + \frac{k^2}{l - h} = \frac{k^2}{h} + h = l;$$

so that C becomes now the centre of oscillation, or the centres of oscillation and suspension are reciprocal.

Kater's Pendulum.—This property was made use of by Captain Kater (Phil. Trans. for 1818) to determine the true length of the seconds pendulum in the following manner.



Let A B be the compound pendulum, C the point of suspension, W and w two weights which may be shifted from one position to another on the pendulum, and O the centre of oscillation of the pendulum, including W and w. The positions of C and O being first determined approximately by computation, knife edges are fixed at these points to form the parallel axes about which the pendulum is to be made to vibrate in the succeeding steps of the experiment. These knife edges are formed and fixed with great care, and being rested alternately upon horizontal agate planes, the weight W is shifted till the times of vibration about C and O are very nearly the same, and the adjustment is then perfected by moving the smaller weight w. The time of vibration is now carefully observed, and the distance C O accurately measured; and if l be this distance, and t the observed time of vibration, and L represent the length of the simple pendulum vibrating seconds, we have, since the lengths of simple pendulums are as the squares of their times of vibration,

$$t^2 : 1^2 :: l : \mathrm{L}, \text{ and } \therefore \mathrm{L} = \frac{l}{t^2}.$$

The corrections to be applied to the length of the simple pendulum for given errors in the construction of the compound pendulum are given in a Paper by Mr. Lubbock in the 'Philosophical Transactions' for 1830. The greatest error arises from a deviation for horizontality in the agate planes,—a deviation of 10′ increasing by about 6 the vibrations in 24 hours.

The construction of this pendulum has since been considerably simplified, consisting in its improved form of a plain straight bar, 2 inches wide, $\frac{1}{2}$ inch thick, and about $62\frac{1}{2}$ inches long. At the distance of 5 inches from one end of this bar is placed the vertex of one of the knife edges, and at the distance of 39 inches is placed the vertex of the other knife edge. The pendulum is made to vibrate nearly in the same time about both knife edges by filing away one of the ends of the pendulum, and the adjustment is perfected by means of two screws, which hold a small weight in a hole near one end of the bar.

The length L of the seconds pendulum having been determined, the accelerating force of gravity at the place of the experiment is immediately given by the equation $g = \pi^2 \mathrm{L}$. Thus in the latitude of London the length of the seconds pendulum, L, is 39·1393 inches, and, consequently,

$$g = \pi^2 \times 39\cdot1393 = 386\cdot29 \text{ inches} = 32\cdot19 \text{ feet}.$$

The force of gravity varies in different latitudes, the increment above the force at the equator being nearly as the square of the sine of the latitude; and since the length of the seconds pendulum is directly proportional to the force of gravity, the increment in its length above the length at the equator varies also as the square of the sine of the latitude. Hence, if 39·0265 be the length of the seconds pendulum at the equator, and 0·1608 the increment in its length at the pole, the length l of the pendulum in any latitude λ, is given by the equation

$$l = 39\cdot0\overset{1677}{\cancel{265}} + \overset{.20027}{\cancel{0\cdot1608}} \sin^2 \lambda.$$

Since the force of gravity without the earth's surface varies in the same latitude inversely as the square of the distance from the earth's centre, and the number of vibrations made by a pendulum in a day varies inversely as the time of vibration,

and therefore directly as the square root of the force of gravity, it follows that the number of vibrations in a day varies inversely as the distance from the earth's centre. If, then, n represent the number of vibrations in a day at the earth's surface, and δn the number of vibrations lost, when the pendulum is carried to the height h above the surface,

$$\frac{n - \delta n}{n} = \frac{r}{r + h} = 1 - \frac{h}{r} \text{ nearly;}$$

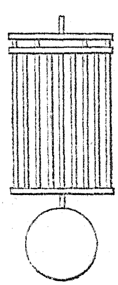
and the number of vibrations lost in a day is given approximately by the equation

$$\delta n = \frac{n h}{r}.$$

Compensation Pendulums.—Besides the variation in the time of vibration of a pendulum arising from the variation of gravity in different latitudes, and at different altitudes, there may be further a source of irregularity in the variation of the actual length of the pendulum, arising from the expansion or contraction of its material under different degrees of heat. To remove this defect, so important an object when the pendulum is employed as a constant time-keeper, various methods have been invented for constructing compensation pendulums, in which, notwithstanding the expansions of their several parts, the length of the equivalent simple pendulum, or distance between the centre of oscillation and the point of suspension, shall remain constantly the same. The first compensation pendulum appears to have been constructed by George Graham, who, after repeated trials, succeeded, in the year 1721, in forming a mercurial pendulum, in which the compensation was found to be so far effected, that its error in the extremes of temperature was reduced to $\frac{1}{8}$th the error in an ordinary pendulum.

The idea of arranging bars of different metals in such a manner as to form a compensation pendulum, having also been suggested by Graham, though he himself failed in accomplishing it, roused the ingenuity of other mechanics, and in 1726, Harrison, a carpenter, of Barton in Lancashire, succeeded in constructing the Gridiron Pendulum. Various modifications of compensation pendulums have since been made, but none have been found to excel the inventions of Graham and Harrison, which are still used in the construction of astronomical clocks.

Graham's Mercurial Pendulum consists of a rod of steel about 42 inches long, branched towards its lower end, so as to embrace a cylindrical glass vessel 7 or 8 inches deep, and having $6\frac{8}{10}$ inches of this depth filled with mercury; but the exact quantity of mercury, being dependent on the weight and expansibility of the other parts of the pendulum, must be determined by experiment. When the temperature increases, the steel rod is lengthened, while the mercury rises in the cylinder; but when the temperature decreases, the steel is shortened, and the mercury falls in the cylinder. By a proper adjustment, then, of the quantity of mercury, the effect of the lengthening or shortening of the rod is neutralized by the rising or falling of the mercury, and the centre of oscillation is kept at an invariable distance from the point of suspension.



Harrison's Gridiron Pendulum consists of five rods of steel and four of brass, placed in an alternate order, the middle rod, by which the bob or weight is suspended, being of steel. These rods are connected by cross pieces in such a manner, that while the expansion of the steel rods has a tendency to lower the bob, the expansion of the brass rods acts upwards, and tends to raise it; so that by duly proportioning the lengths of the two classes of rods, the centre of oscillation is kept at an invariable distance from the point of suspension, and the length of the equivalent simple pendulum remains constantly the same.

Amongst those who have succeeded in constructing compensation pendulums may be mentioned Regnault, Deparcieux, Julien le Roy, Ellicot, Hooke, F. Berthoud, Troughton, Dr. G. Fordyce, Ward, Adam Reid, Doughty, Ritchie, and Hardy.

Since the isochronism of the vibrations, independently of the length of the arc of vibration, is peculiar to pendulums vibrating in cycloidal arcs, it might be supposed that it would be advantageous to make the pendulum vibrate between cycloidal cheeks; and such a construction was in fact adopted for some time after its first invention by Huygens. Upon further consideration, however, it appears that in this case the centre of oscillation no longer occupies the same point of the pendulum in different parts of its path, from the circumstance of the virtual point of suspension, which is now the point of contact with the cycloidal cheek, continually varying. The vibrations of a compound pendulum, then, between cycloidal cheeks are not isochronous, nor has the theory of their motion been ever investigated, that we are aware of. Further objections to such pendulums also arise from the difficulty of giving to the cheeks the true cycloidal form, and the improbability of their long retaining it, supposing it once given.

The vibrations of actual pendulums are manifestly affected by the resistance of the air, the friction at the axis of suspension, and the maintaining power which is necessary to keep the pendulum vibrating for any length of time. Professor Airy, in the 'Cambridge Philosophical Transactions,' 1826, has determined, by the principle of the variation of parameters, general formulæ remarkable for their simplicity, for the alteration in the time and extent of the vibrations of a pendulum when acted upon by any small disturbing force whatever. By applying these formulæ to the disturbing forces above mentioned, it appears that, though the arc of vibration is diminished, the time of a vibration is not affected either by a constant friction at the axis of suspension, or by the resistance of the air; and further, that if an impulse be given to the pendulum at its lowest point only, the time of vibration remains unaltered. In the dead-beat escapement, the maintaining power acts on the pendulum for a small space near the middle of the vibration only, and Professor Airy, in the Paper above referred to, comes to the conclusion that this escapement is far superior to any other.

Ballistic Pendulum, *Cannon Pendulum*, and *Musket Pendulum*.—The name *ballistic pendulum* was given by Robins to an apparatus invented by him for ascertaining the velocities of military projectiles, and thence comparing the effective powers of different specimens of gunpowder. This apparatus consisted of a large block of wood, suspended vertically by a strong horizontal axis to which it was attached by a firm iron stem. Of late years, however, considerable improvements have been made by the Military Engineers of France in the details of the construction of ballistic pendulums, and the arms themselves from which the projectiles are fired have been suspended and adjusted, so as to form pendulums of equal value, and to measure by their arc of recoil the force of the explosion. To these suspended guns, as well as the suspended blocks which receive the shot, the French have extended the name ballistic pendulum, while they distinguish the one from the other by giving to the latter the name of the receiver pendulum, and to the former that of cannon pendulum, musket pendulum, &c., according to the nature of the arms suspended. English and American writers, however, still restrict the term ballistic pendulum to that which receives the shot.

The principal conditions to be fulfilled, as far as possible, by the construction of the pendulum, are—

1. That the pendulum should be capable of sustaining, without injury, the impact of balls of the largest calibre intended to be received by it, moving with the greatest velocity that can be given to them.

2. That the *core*, or part of the block which receives the impact of the ball, should be susceptible of being easily and quickly renewed after each fire.

3. That the frame of the cannon pendulum should be capable of receiving guns of various calibres.

4. That arrangements should be made in each pendulum for adjusting the height of its centre of oscillation, so as to make it coincide with that of the line of the fire, in order to prevent violent shocks on the axis of motion.

5. That the apparatus should not be liable to be affected by hygrometric changes in the atmosphere.

We proceed to describe briefly the contrivances by which, in the most improved forms of the pendulum, it has been sought to fulfil the above conditions.

The *pendulum block* is of cast iron, in the form of a hollow frustrum of a cone, with a hemispherical bottom; and in order to give it the requisite strength, it is closely hooped with wrought iron over all the conical part, except in the places where it is embraced by the suspension straps. In the hollow of the pendulum block is placed the core, which is to receive the shot, and its axis should therefore coincide with the line of fire.

The opening in the face of the block is partially closed by an iron plate; and the point struck by the ball is marked by the hole made in a sheet of lead, which is placed over the opening in the plate, and retained by a washer, or smaller iron plate, bolted to the large one. Vertical and horizontal scales, drawn on the face of the small plate, serve, by means of an easy reference, to measure the position of the point struck by the centre of the ball.

Core of the pendulum block.—The hemispherical bottom of the core is formed of a block of lead, which serves to counterpoise the weight of the front part of the block, and thus facilitates the adjustment of the axis in a horizontal position.

The sand which receives the impact of the balls is contained in cases made of strong leather stretched over iron frames: the ends of these cases are closed with soft boards about $\frac{3}{8}$ inch thick. In order to fill one of these cases or bags, it is placed on its small end, the boards forming the bottom are laid down on pins intended to support them, and if there be any openings through which the sand might escape, they are closed with shavings, &c.: the sand is then put in and settled with a small rammer. When nearly filled, the bag is placed on the platform of a balance, and its weight properly adjusted; after which the boards forming the head are fastened on by small nails driven into wooden plugs in holes on the inside of the hoop which forms the larger end of the frame.

Four of these bags form a set for filling the pendulum block; and an interval of about 3 inches is left at the mouth of the block to admit any compensating weights which may be required to make up the proper charge, and which are in the form of large rings, made of iron, of different sizes, according to the weight required. The vacant space in the mouth of the block is requisite for containing the sand displaced by the shot.

Suspending apparatus.—The block is attached by means of four straps of wrought iron to a horizontal shaft of the same material. The shaft terminates at each end in knife edges made of hardened steel welded to the iron: these knife edges are rounded on a radius of 0·06 inch, and rest in v's, the bottom parts of which are rounded on a radius of 0·1 inch; while the inclination of the sides of the v's is so arranged with reference to that of the planes of the knife edges as to allow the pendulum to vibrate through an arc of 30°. The adjustment of the v's is regulated by means of wedges.

The arc of vibration of the pendulum is measured on a brass limb; a slide, also of

brass, moving on this limb, is pushed forward by an index attached to a bar, which is connected with the suspension straps at the proper distance from the axis.

In the *cannon pendulum*, the suspension frame, the supports, and the general arrangement, are similar to those of the ballistic pendulum, as described above.

In the *musket pendulum*, and the ballistic pendulum for practice with the *musket*, the principles of construction are the same, the chief deviation being in the manner of forming the core: this core in the French pendulum consisted of a block of lead, which received the ball, and which was renewed at each shot; but Captain Mordecai, of the United States' Ordnance Department, in his experiments at Washington in the years 1843–44, substituted a core composed as follows:

1st. A block of hard wood, turned to fit the bottom part of the pendulum block.

2nd. A conical block of lead, faced with a plate of iron, occupying nearly the centre of the core.

3rd. A block of hard wood, turned and cut to such a length as just to fill the pendulum block, and to bear against the face-plate, which is formed of wood and pressed against the front of the pendulum by an iron clamp. The point struck by the ball is marked by the perforation of the face-plate.

Adjustments of the pendulums.—The pendulums must always be adjusted for the positions of the centres of gravity and oscillation, for the horizontality of their shafts, and when the ballistic and cannon or musket pendulums are used together, the shafts of the two pendulums must be adjusted for parallelism.

Adjustment of the shafts.—This adjustment is corrected, if necessary, by moving one or more of the seats in which the v's are placed. It is verified for horizontality by a level; and for the parallelism of the two shafts as follows: Two plumb-lines are suspended to the ends of a needle attached to each shaft in a direction perpendicular to its axis; four other plumb-lines are suspended in the axis of the gun and block (on the front and rear of each), and when the adjustment is perfect, these eight plumb-lines should hang in the same plane.

Adjustment of the centres of oscillation.—The centre of oscillation of each pendulum must coincide very nearly with the line of fire; and its position having been determined in the manner hereafter to be explained, it is to be raised or lowered, if necessary, by placing weights on the upper or lower of the large screw-bolts which connect the front and rear straps above and below the gun or the block.

Adjustment of the centre of gravity.—The centre of gravity must be situated in the intersection of the vertical plane containing the axis of the cannon or block and the plane perpendicular to this axis which passes through the axis of motion. Deviations from the proper position of the centre of gravity may be caused by variations in the charge of the gun or block. This adjustment is corrected by sliding backwards or forwards the weights which have been placed upon the large screw-bolts to adjust the centre of oscillation.

Moments of the pendulums.—By the moment of a pendulum we mean the product of its weight and the distance of the centre of gravity from its axis of motion, the weight being estimated in pounds, and the distance in feet. This moment ought to be determined with precision, since it enters into the formulæ for determining the velocity of the projectile. The weights of the several parts of the pendulums being accurately determined, and also the positions of their centres of gravity by balancing them on the edge of a square steel bar, the places of the centres of gravity of the entire systems, or the moments of these systems, are easily calculated by the ordinary formulæ; and by the same means the corrections for an alteration of the adjusting weights, or a change in the weight of the core of the block, or of the charge of the gun, are readily obtained. The results of these calculations may be verified at any

time experimentally, without dismounting the pendulums, in the following manner: A cord being fixed at any convenient point of one of the pendulums, is passed over a fixed pulley, and by means of a known weight attached to its extremity, pulls the pendulum through an angle which is accurately measured. The pulley should be large, turning on a small and well-greased axis, so that the friction may be neglected without introducing any appreciable error. Now having marked conspicuously the intersection with the surfaces of the block or gun of the plane passing through the axis of motion and the centre of gravity, which plane is vertical when the pendulum hangs freely, the inclination of this plane under the action of the weight, which is the angle through which the pendulum is pulled, is easily observed.

Let, then, p represent the weight of the pendulum;

h, the unknown distance of its centre of gravity from the axis of motion;

α, the angle through which the pendulum is pulled;

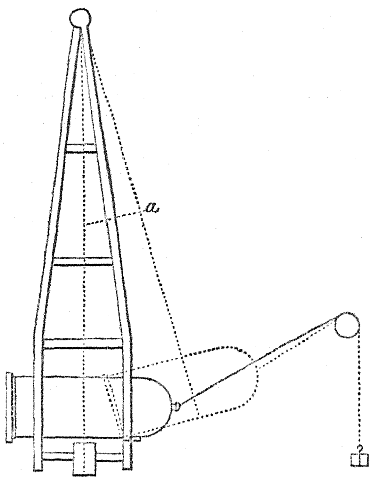
d, the perpendicular let fall from the axis of motion on the direction of the cord;

t, the tension of the cord, or the weight suspended from its extremity; and we have the relation

$$t\,d = p\,h \sin \alpha;$$

and hence the required moment $p\,h$ is given by the expression

$$p\,h = \frac{t\,d}{\sin \alpha}.$$



Position of the centre of oscillation.—The distance of the centre of oscillation from the axis of motion, or length of the equivalent simple pendulum, is obtained by setting the pendulum in motion and observing the time of a certain number of vibrations. Thus, if n be the number of vibrations in the time t, g the force of gravity at the place of observation, π the ratio of the circumference of a circle to its diameter, and l the distance of the centre of oscillation from the axis of rotation,

$$l = \frac{g\,t^2}{\pi^2\,n^2};$$

or if L be the length of a seconds pendulum at the place of observation,

$$l = \frac{\mathrm{L}\,t^2}{n^2}.$$

When the distance l' of the centre of oscillation from the axis of rotation is ascertained for any given condition of the system, the adjusting weight w, requisite to bring that centre to any desired distance l, may be computed very nearly by the formula

$$w = \frac{p\,h\,(l - l')}{d\,(d - l)},$$

$p\,h$ being the moment of the pendulum, and d the distance of the adjusting weight from the axis of rotation.

Formulæ for computing the velocity of the ball.

1. *By the ballistic pendulum:*

Let p represent the weight of the pendulum.

h the distance of its centre of gravity from the axis of motion.

l ,, ,, oscillation ,, ,,

i ,, the point of impact ,, ,,

b the weight of the ball.

v the velocity with which the ball strikes the pendulum.

α the angle of the first semi-vibration of the pendulum.

The mass of the ball being $\frac{b}{g}$, its quantity of motion at the instant of impact is $\frac{b\,v}{g}$, and the moment of this quantity of motion about the axis of motion is $\frac{b\,v\,i}{g}$.

After the impact, all parts of the pendulum, including the ball, move with the same angular velocity; and if ω represent this angular velocity, the quantity of motion communicated to an element $d\,m$ at a distance r from the axis of motion is $\omega\,r\,d\,m$, and the moment of this quantity of motion about the axis is $\omega\,r^2\,d\,m$. The sum of all such moments, or the moment of the quantity of motion of the whole pendulum, is $\omega \int r^2\,d\,m$, the integral being taken for every particle of the pendulum, including the ball. Now, by the previous adjustment of the pendulums, the point of impact cannot be far from the centre of oscillation, and the position of this centre may therefore be assumed to remain constant without introducing any sensible error. We have therefore

$$l = \frac{\text{moment of inertia}}{\text{moment of the mass}} = \frac{\int r^2\,d\,m}{\frac{p}{g}\,h + \frac{b}{g}\,i};$$

and hence

$$\omega \int r^2\,d\,m = \omega \,.\, \frac{(p\,h + b\,i)\,l}{g};$$

and, since this must be equal to the moment of the quantity of motion of the ball before impact,

$$\frac{b\,v\,i}{g} = \omega \,.\, \frac{(p\,h + b\,i)\,l}{g},$$

$$\text{and } v = \omega \,.\, \frac{(p\,h + b\,i)\,l}{b\,i}.$$

The velocity of the centre of oscillation is $l\,\omega$, and since this point moves as though it were isolated, its velocity at the lowest point of its course is also that due to an altitude equal to the versed sine of the angle of semi-vibration; so that

$$l\,\omega = \sqrt{2\,g\,l\,(1 - \cos\alpha)} = \sqrt{2\,g\,l\,.\,2\,\sin^2 \tfrac{1}{2}\alpha} = 2\sin\tfrac{1}{2}\alpha\,\sqrt{g\,l};$$

$$\text{and therefore } v = 2\sin\tfrac{1}{2}\alpha\,\frac{(p\,h + b\,i)\sqrt{g\,l}}{b\,i}.$$

In a set of experiments with balls of the same kind and calibre, since $b\,i$ is small in comparison with $p\,h$, no sensible error will be introduced by assigning to $b\,i$ in the numerator of the above expression a constant value equal to the mean weight of the balls, multiplied by the mean distances of the points struck from the axis of suspension. By this assumption the whole term $(p\,h + b\,i)\sqrt{g\,l}$ becomes constant for one

set of experiments; and the value of this term being found, the formula is extremely simple and adapted to logarithmic computation. Since $2 \sin \frac{1}{2} \alpha =$ chord of α, the velocity is directly proportional to the chord of the arc of semi-vibration, and inversely proportional to the product $b\, i$.

2. *By the gun pendulum.*—The same notation being employed as for the ballistic pendulum, the moment of the quantity of motion of the pendulum is

$$\omega \frac{p\, h\, l}{g} = 2 \sin \tfrac{1}{2} \alpha \frac{p\, h}{g} \sqrt{g\, l}.$$

As the ball and wad leave the muzzle of the gun together, their quantity of motion is $\frac{(b + w)\, v}{g}$, w being the weight of the wad. The expansive force of the gunpowder which produces this quantity of motion may be considered as acting on an area of a great circle of the ball; and as it acts with equal intensity on the annulus between the ball and the bore, driving out a portion of the elastic fluid past the ball, the quantity of motion will be increased by this circumstance in the proportion of the area of the cross section of the bore to that of a great circle of the ball, or in the proportion of the square of the diameter of the bore to the square of the diameter of the ball. The quantity of motion, therefore, of the ball and wad, and of the fluid which escapes past the ball, all taken together, is

$$\frac{(b + w)\, v}{g} \times \frac{D^2}{d^2},$$

and its moment about the axis of suspension is

$$\frac{(b + w)\, v\, i}{g} \cdot \frac{D^2}{d^2},$$

D and d being the diameters of the bore and ball respectively, and i being now the distance from the axis of suspension to the axis of the gun.

Again, if c' be the weight of the cartridge, including the bag, and the elastic fluid behind the ball be assumed to have a mean velocity equal to half that of the ball at the moment the ball leaves the gun,* the quantity of motion of the inflamed powder and of the cartridge-bag is represented approximately by $\frac{1}{2} \frac{c'\, v}{g}$, and its moment with respect to the axis of suspension by $\frac{1}{2} \frac{c'\, v\, i}{g}$.

After the ball has left the gun, the elastic fluid still continues to expand, and, in consequence of the resistance of the air, to re-act on the pendulum and increase its recoil. The quantity of motion due to this cause may be considered proportional to the quantity of powder in the charge, and may therefore be represented approximately by $\frac{c\, m}{g}$, c being the weight of the powder, and m a constant multiplier to be determined by experiment. The moment, then, of this quantity of motion about the axis of suspension is $\frac{c\, m\, i}{g}$.

The sum of the moments of all the quantities of motion of the ball and the charge is therefore

$$\frac{(b + w)\, v\, i}{g} \cdot \frac{D^2}{d} + \frac{1}{2} \frac{c'\, v\, i}{g} + \frac{c\, m\, i}{g},$$

and this must be equal to the moment of the quantity of motion of the pendulum; so that

* Hutton, 37th Tract. Prob. 19.

$$\frac{(b+w)\,v\,i}{g}\cdot\frac{D^2}{d^2}+\tfrac{1}{2}\,\frac{c'\,v\,i}{g}+\frac{c\,m\,i}{g}=2\sin\tfrac{1}{2}\,a\,\frac{p\,h}{g}\sqrt{g\,l};$$

and hence

$$v=\frac{2\sin\frac{1}{2}\,a\,\dfrac{p\,h\sqrt{g\,l}}{i}-c\,m}{(b+w)\cdot\dfrac{D^2}{d^2}+\dfrac{c'}{2}}$$

To prevent the ballistic pendulum from being acted upon by the blast of the gun, the cannon pendulum should be placed at a distance from the ballistic pendulum of not less than 50 feet, and a screen should be placed at some little distance in front of the face of the pendulum block, with a hole in it of about 12 inches diameter, for the passage of the shot.

The musket pendulum may be set up at about 10 feet distance from its ballistic pendulum, and a screen, having in it a hole of about 2 inches diameter, should be placed in front of the face of the pendulum block, at some little distance, say 2 feet.

Captain Mordecai, from the results of his experiments at Washington, draws the conclusion, that the only reliable mode of proving the strength of gunpowder is to test it with Service charges, in the arms for which it is designed, for which purpose the pendulums are perfectly adapted.

For powder to be used in cannons, he advises the cannon pendulum alone to be made use of, as its indications correspond remarkably well with those given by the ballistic pendulum, and the use of the large ballistic pendulum is difficult, slow, and expensive. For the proof of powder for small arms, he recommends the small ballistic pendulum to be fired at from a barrel set in a permanent frame.

The same gentleman states that in a 24-pounder gun new cannon powder should give, with a charge of ¼th, an initial velocity of not less than 1600 feet, to a ball of medium weight and windage; and that the initial velocity of the musket-ball of 0·05 inch windage, with a charge of 120 grains, should be—

With new musket powder,	not	less than	1500	feet.
With new rifle powder,	,,	,,	1600	,,
With fine sporting powder,	,,	,,	1800	,,

He also comes to the conclusion, that the common éprouvettes are of no value as instruments for determining the relative force of different kinds of gunpowder.

PENETRATION OF PROJECTILES.*—The following Tables and Notes relate chiefly to the effects of artillery on fortifications and buildings connected therewith,—its powers in the field under various conditions and positions being foreign to the principal object.

The information whence these notices are derived has been taken from the 'Aide-Mémoires' in the French Service, 'Journal des Sciences Militaire,' &c.; Belidor, &c. Several notes have been forwarded to me by individuals, and are included; a few are my own. The French measures and weights have been frequently retained, having in some instances their equivalents given in English terms.

The following Table is the result of the experiments at Metz, and of calculations founded thereon, according to Hutton's Theory.

* By Colonel Emmet, R. E.

Penetration into Masonry, good Rubble, as that of the Revetments at Metz constructed by Vauban. (Aide-Mémoire à l'Usage des Officiers d'Artillerie.)

Boulets.	Charges.	Aux Distances de Mètres.									English Measures.	
		25	50	100	200	300	400	600	800	1000	Diam. of Shot.	Charge Avoirdup.
	k.	m.	m.	m.	m.	m.	m.	m.	m.	m.	inches.	lbs.
36	6·00	0·680	0·670	0·650	0·605	0·565	0·530	0·455	0·380	0·310	6·648	13·234
	6·00	0·650	0·640	0·615	0·570	0·530	0·490	0·415	0·340	0·275	5·808	13·234
	4·00	0·615	0·605	0·580	0·535	0·495	0·460	0·385	0·310	0·250	..	8·823
24	3·00	0·575	0·565	0·545	0·505	0·465	0·425	0·350	0·285	0·230	..	6·617
	2·00	0·510	0·500	0·480	0·440	0·400	0·365	0·300	0·245	0·200	..	4·411
	1·50	0·440	0·430	0·410	0·370	0·335	0·300	0·245	0·200	0·165	..	3·309
	4·00	0·570	0·555	0·530	0·485	0·445	0·405	0·325	0·255	0·195	5·074	8·823
	2·67	0·535	0·525	0·500	0·455	0·415	0·375	0·300	0·235	0·185	..	5·888
16	2·00	0·495	0·485	0·465	0·425	0·385	0·350	0·275	0·215	0·170	..	4·411
	1·33	0·435	0·425	0·410	0·370	0·330	0·295	0·230	0·185	0·150	..	2·94
	1·00	0·380	0·370	0·350	0·310	0·275	0·240	0·190	0·155	0·130	..	2·206
	2·00	0·480	0·470	0·445	0·405	0·370	0·330	0·255	0·195	0·155	4·610	4·411
12	1·50	0·450	0·440	0·420	0·380	0·340	0·300	0·225	0·175	0·140	..	3·309
	1·00	0·395	0·385	0·365	0·330	0·290	0·255	0·190	0·155	0·125	..	2·206
	0·75	0·350	0·340	0·320	0·280	0·245	0·210	0·165	0·135	0·110	..	1·654
8	1·25	0·405	0·395	0·375	0·335	0·295	0·260	0·190	0·140	0·105	4·027	2·757

NOTES ON THE TABLE.

The above penetrations multiplied by

1·25 will give the penetration into masonry of moderate quality.
1·75 " " brick.
0·46 " " oolitic calcareous rock.

1. Shot fired at short distances from the wall, perpendicular to it, formed an *entonnoir*, the exterior diameter of which equalled five times the diameter of the shot,—the internal opening being cylindrical,—scattering splinters to a distance of 40 or 50 metres, and forming a train of fragments in front of 6 metres.

The shock of the shot loosens the masonry to a distance one-half greater than the diameter of the exterior of the opening, being for the 24-pr. = 1·15 metre; for the 16-pr. = ·90; for the 12-pr. = ·80.

2. Shot fired against masonry with a charge of one-quarter their weight, usually break on a meridional plane of which the pole is the striking point.*

3. The effect of shells on masonry is little; they break the moment of striking with an ordinary charge, and with low charges make but little impression.†

4. By the trials at Metz, it appears that a masonry scarp may be breached at the distance of 40 to 60 metres by oblique fire; with a charge of ½ the weight of the shot, at an angle of 25° to 30°; and with that of ⅓rd at an angle of 40° to 45°.

5. The effect of shot of different calibres in breaching is nearly proportional to their weight,‡ (charges, it is presumed, being proportionate.)

* This remark applies to shells: whether hollow shot have been fired against masonry I am not aware. The 8-inch shell weighs from 42 to 44 lbs.; the 8-inch hollow shot about 56 lbs.

† In 1810, trials were made at Glatz with shells from a 24-pr. against a wall of cut stone and brick, well built, and of several years' standing: the wall was 16 ft. long, 7 high, and 4½ thick. The charges varied from 1¾ lb. to 5¼ lbs. In every instance the shell was completely splintered,—the penetration into the masonry being from 9 to 18 inches,—the diameter of the opening from 1 foot 6 inches to 2 feet 7 inches; but the wall was not in the least shaken by them: but a single 24-lbs. shot fired from a howitzer with a charge of 1¾ lb. sensibly shook the wall and cracked it. The fuzes of the shell would have fired the charges about half the number of rounds.

‡ On comparing the number of rounds and the time requisite for making breaches with the 24-pr.

6. The heat produced by the concussion is great, particularly when the shot break. In both cases the lime appears to be partially calcined.

Experiments at Fort Monro Arsenal (United States) in 1839.

Calibre.	Charge.	Elevation.		Distance.	Mean Penetration.		
					Dressed Granite.	Potomac Freestone.	Hard Brick.
	lbs.	°	′	yds.	in.	in.	in.
Shot.							
32-pr. gun	8	1	0	880	3·5	12·	15·25
Shell.							
8-inch sea-coast howitzer	6	1	35	880	1·	4·5	8·5

The solid shot broke against the granite, but not against the freestone or brick. The shells broke into small fragments against each of the three materials.

The circumstances attending the penetration of the shot and shells corresponded with those above stated in the experiments at Metz. The walls used as targets were built of dressed stone, and of the best bricks, laid in hydraulic cement; but being isolated walls (10 feet square of each material, and 5 feet thick, with 3 counterforts), and being battered before the masonry was perfectly set, the effect of the projectiles in shattering the masonry around the point struck was greater than indicated by the experiments referred to at Metz.

VARIOUS NOTES.

1. Effects of a long 24-pr. on a scarp of columnar basalt of the Rhine, generally raised in blocks of 4 to 5 feet by 8 to 10 inches in diameter,—frequently used as headers,—distance 160 feet,—

   charge of 10 lbs.—penetration into the basalt 10 inches.
   „ 4 lbs. „ „ 4 inches.

   Twenty rounds were fired, giving the same results.

2. Bermuda hard limestone walls of rubble masonry with ashlar facings of 2′ × 1′ × 1′ 6″, being an old lime-kiln. At 40 feet, three rounds of a 32-pr. of 9 feet 6 inches were fired: the first two penetrated 5 feet 6 inches each; the third, entering the first opening, passed through the wall, which was 8 feet 6 inches thick, and struck the opposite side.

3. A masonry embrasure was ruined at 175 yards by 15 rounds from a 24-pr., 10lbs. charge,—and another in 20. (Neither place nor particulars have been given me.)

4. *Effects on concrete.*—A magazine built at Woolwich for the purpose of experiment: span of arch 18—rise $\frac{1}{3}$ to $\frac{1}{4}$—thickness nearly 4 feet; abutments 4′ 6″ to springing of arch—thickness 7′ 6″—dos d'âne on the arch. Five shells were fired at 45° from two 13-inch mortars, distant 500 yards,—shells loaded with sand, weighing 200 lbs. All struck the building,—two only fairly upon the arch, which they penetrated to about $\frac{1}{3}$rd their own diameter, pulverizing the concrete 10 to 12 inches, forming craters 2 feet and 2 feet 6 inches diameter. The arch was cracked by each, vertically from the side of the crater—the cracks shewing themselves through on the soffit of the arch. The two struck on the same horizontal plane, distant 4 feet 6 inches, and a crack was made between the two craters.

Two shells were fired at 75° elevation; the effect of one on the rear of the building was similar to those at 45°; the other entered the crater of one of the first, enlarged it to 3 feet, and pulverized the concrete to 15 inches deep.

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and 16-pr. (Metz), their proportions appear to be in an inverse ratio to the weight, being nearly as 16 to 22. In both cases the consumption of powder and of shot was nearly equal.

Two shots fired at the abutments from a 24-pr., distant 250 yards, penetrated about 3 feet 10 inches, forming craters 3 feet diameter, and casting a few splinters to a distance of 40 to 50 yards. These likewise cracked the mass, and judging from the effects of two shots subsequently fired, it is probable the arch would soon have been brought down.

It is to be remarked that the abutments, built on soft ground, had settled considerably, and split the arch along its entire length, forming a crack $\frac{3}{10}$ inch open—this before trial—and that the concrete was not dry.

5. At the siege of Landau, on a magazine of Vauban's construction, upwards of 80 shells fell without doing it any damage; the same occurred at Ath and other places. At that of Tournay, upwards of 45,000 shells were thrown into the citadel, of which the greatest number fell on two similar magazines, semicircular arches, as at Landau, without doing them any damage; whilst two souterrains arched *entiers point*, and covered over for 40 years with 5 to 6 feet of earth, were *enfoncé*. All Vauban's have stood without failure.—(*Belidor.*)

6. At the siege of the Castle of Scylla in 1806, a battery of field-guns was placed in a position to bear into the embrasures of the casemates, out of view of the artillery of the castle. On the fall of the castle, the effects of the fire exhibited by the indentations of the walls, and other marks of destruction and slaughter, proved that, under the usual construction of the embrasure, casemates would be untenable, if exposed to direct fire.—(*Jones.*) (See article 'Breach,' vol. i.)

Penetrations in settled Ground, half Clay, half Sand.

Shot.	Charge.	Distances in Metres.									English Measures.	
		25	50	100	200	300	400	600	800	1000	Diam. of Shot.	Charge Avoirdupois.
	k.	m.	m.	m.	m.	m.	m.	m.	m.	m.	inches.	lbs.
36	6·00	2·77	2·70	2·60	2·47	2·37	2·27	2·09	1·92	1·77	..	13·234
24	6·00	2·75	2·67	2·52	2·31	2·14	2·02	1·84	1·68	1·54	..	13·234
	4·00	2·55	2·48	2·35	2·18	2·06	1·96	1·78	1·62	1·48	..	8·823
	3·00	2·35	2·29	2·20	2·07	1·97	1·88	1·71	1·57	1·45	..	6·617
	2·00	2·12	2·09	2·03	1·92	1·83	1·75	1·59	1·45	1·33	..	4·411
	1·50	1·94	1·90	1·84	1·75	1·67	1·60	1·46	1·32	1·20	..	3·309
16	4·00	2·40	2·31	2·18	1·97	1·83	1·72	1·56	1·42	1·28	..	8·823
	2·67	2·20	2·12	2·02	1·87	1·76	1·67	1·52	1·38	1·25	..	5·888
	2·00	2·05	1·99	1·91	1·77	1·69	1·61	1·47	1·33	1·20	..	4·411
	1·33	1·85	1·80	1·73	1·65	1·57	1·50	1·36	1·24	1·13	..	2·94
	1·00	1·69	1·66	1·62	1·54	1·47	1·40	1·28	1·16	1·05	..	2·206
12	2·00	1·65	1·61	1·52	1·39	1·29	1·22	1·09	0·98	0·89	..	4·411
	1·50	1·54	1·50	1·42	1·32	1·24	1·17	1·05	0·95	0·86	..	3·309
	1·00	1·39	1·36	1·29	1·22	1·15	1·09	0·98	0·89	0·82	..	2·206
	0·75	1·27	1·24	1·20	1·13	1·06	1·01	0·92	0·84	0·78	..	1·654
8	1·25	1·43	1·39	1·32	1·19	1·10	1·02	0·90	0·81	0·73	..	2·757
Howitzers.												
22c.	2·00	1·23*	1·20*	1·15*	1·06	0·98	0·90	0·77	0·66	0·59	8·661	4·411
	1·50	1·09*	1·06	1·02	0·94	0·86	0·79	0·69	0·61	0·55	..	3·309
	1·00	0·88	0·86	0·82	0·75	0·70	0·65	0·58	0·53	0·49	..	2·206
	0·50	0·58	0·57	0·55	0·53	0·51	0·49	0·45	0·42	0·40	..	1·103
16c.	1·50	1·34*	1·30*	1·24	1·14	1·04	0·95	0·78	0·64	0·56	6·299	3·309
	1·00	1·15	1·12	1·08	0·98	0·89	0·81	0·67	0·57	0·50	..	2·206
	0·75	1·01	0·98	0·94	0·85	0·78	0·71	0·60	0·52	0·46	..	1·654
15c.	1·00	1·13*	1·09*	1·04*	0·93	0·83	0·74	0·59	0·48	0·41	5·906	2·206
	0·50	0·85	0·82	0·78	0·70	0·63	0·57	0·46	0·39	0·34	5·906	1·103
12c.	0·27	0·69	0·67	0·63	0·55	0·49	0·44	0·37	0·31	0·26	4·724	·595
Wall-pieces.	0·010	0·25	0·27	0·22	0·15	0·11	0·08	0·04				
	0·008	0·30	0·28	0·24	0·19	0·15	0·12	0·08				

Note.—At the experiments at Metz, after breaching the masonry with 24-prs. at a distance of 31·9 metres, shells were fired from the 24-prs. and from 8-inch howitzers, to raze the parapet. The effect of the former was very inferior to that of the latter. Of the 8-inch shells, eighteen were fired loaded with 4·4 lbs., 2·2 lbs., and 3·3 lbs. charges (English). Of these, sixteen burst in the parapet with great effect. Previous trials had shewn that with a higher charge the shells split in striking sand. The parapet was reduced to 2 feet in thickness, and the firing discontinued.

With high charges, and at short distances, shells often split,—marked thus (*) in the preceding Table.

Penetrations in other Earths, obtained by multiplying the above numbers by the following factors:

Sand mixed with gravel	0·63
Earth mixed with sand and gravel, weighing above twice that of water	0·87
Settled vegetable soil, a made ground, sand and clay	1·09
Humid stiff clay	1·44
Earth lightly settled	1·50
Earth recently removed	1·90

Sand, a sandy ground mixed with gravel, small stone, and chalk, resist shot better than strong clayey ground, or that which imbibes and retains water.

When earth is softened by long rains, or the melting of snow, shells penetrate nearly double the distance; the fuzes, if not driven home, are generally broken, and at times the shell is broken at the fuze-hole.

Penetrations of Shells in Earth, Wood, and Masonry.

Degrees.	Distances.	Settled Earth. 22c.	27c.	32c.	Oak Wood. 22c.	27c.	32c.	Rubble Masonry of good quality. 22c.	27c.	32c.
	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.
30	600	0·20	0·45	0·50	0·10	0·20	0·22	0·05	0·09	0·10
30	1200	0·25	0·65	0·70	0·12	0·30	0·35	0·06	0·12	0·13
45	600	0·30	0·50	0·55	0·15	0·25	0·27	0·08	0·10	0·11
45	1200	0·40	0·70	0·75	0·20	0·35	0·40	0·10	0·14	0·15
60	600	0·50	0·75	0·80	0·22	0·33	0·37	0·11	0·15	0·16
60	1200	0·55	0·80	0·85	0·25	0·35	0·40	0·12	0·16	0·17
Under the greatest force of descent,		0·60	0·85	0·90	0·25	0·35	0·40	0·12	0·17	0·18

22 centimetres = 8·661 inches English; 27 = 10·630; 32 = 12·599.

NOTES.

1. A battery of 24-prs. in breaching earthwork at 600 metres will consume from three to four times the ammunition required at 40 metres.
2. By experiment in Silesia, four shells of 6 po. 1 lig., and twenty-two of 24 lbs., fired with full charge, formed a breach in an earthen rampart, having a slope of 15° from the vertical, at a distance of 125 metres, of 8 feet wide at the summit, and 24 feet at the base.
3. Penetration of shells fired at 45° elevation into a firm earthen parapet:

$5\frac{3}{5}$ inches	at	600 paces	6 inches.
$6\frac{1}{2}$,,		800 ,,	1 foot.
9 ,,		2500 ,,	$2\frac{1}{3}$ feet.
11 ,,		900 ,,	2 feet.
11 ,,		2800 ,,	3 feet.

4. At Strasburgh, three 12-inch shells, loaded with 13 lbs., were buried in strong earth at the following depths:

4 feet deep—the diameter of the entonnoir was				8 feet.
6	"	"	"	12 feet.
7	"	"	"	15 feet.

5. At Glatz, a very firm earthwork, 18 feet thick and 15½ high in front, was subjected to the fire of 5⅔-inch shells from 24-prs. at the distance of 500 paces; charge, 5 lbs.; bursting charge, 13 oz. After 100 rounds, of which 33 burst in the parapet, an accessible breach was made; and after 220 more rounds, of which 93 burst in the parapet, all cover was destroyed. It was thence concluded that 200 rounds of 5⅔-inch shells would, under similar circumstances, form a breach 18 fathoms long.
6. A field-battery, 12 feet thick, having three embrasures and ditch in front, was rendered untenable by 100 rounds from a 12-pr. howitzer at 500 paces; 39 shells burst in the parapet.
7. At Berlin, in 1802, howitzers of 10 lbs. and 7 lbs. were placed on a glacis before the face of a bastion of mixed earth which had been constructed twenty years, to ascertain penetration, and whether the fuzes would ignite the charge of the shells. The penetration varied from 2 to 3¾ feet with a charge of 2½ for the 10 lbs., and from 1 foot to 2⅓ for the 7 livres with 1½ lb. charges. In each case the fuzes would have fired the powder half the number of rounds.

Results of Experiments at St. Omer in 1799, *and at La Fere in* 1817.

With the ordinary charge.	In an old parapet at 117 metres.		Parapet of recent construction, 105 metres.	
Field Guns.	Mean.	Extreme.	Mean.	Extreme.
4-pr.	179c.	195c.	222c.	245c.
6 "	211	219	271	281
8 "	244	276	321	325
12 "	322	325	383	470
Siege Guns.				
16-pr.	352	395	383	410
24 "	414	436	526	550
Gribeauval's Howitzer, chamber full . .	70	73	88	92
At 80 metres	104	111	130	138
With the charge equal to ⅔ weight of shot at 40 metres:				
16-pr.		490		519
24 "		530		659

Effects of Shells loaded with Service Charge.

	Howitzers of				Mortars of		
	12c.	15c.	16c.	22c.	22c.	27c.	32c.
Number of splinters (average)	17	22	21	33	33	18	22
Number of splinters weighing more than 0·1 kil. .	14	19	17	28	28	18	22

Cen.		E. ins.*
12	=	4·724
15	=	5·906
16	=	6·299
22	=	8·661
27	=	10·630
32	=	12·599

1. On sinking into the ground and bursting, the entonnoirs are generally from two to three times the depth in diameter. With small charges no entonnoir is formed.

* The centimetre is 0·394 of an inch.

2. Splinters are often thrown to a distance of 600 to 800 metres.
3. The effects of very large shells are less in proportion than their weight.

Penetrations into Oak.

Shot.	Charge.	Distances in Metres.								
		25	50	100	200	300	400	600	800	1000
	k.	m.	m.	m.	m.	m.	m.	m.	m.	m.
36	6·00	1·66	1·63	1·58	1·48	1·38	1·29	1·12	0·95	0·80
24	6·00	1·60	1·56	1·50	1·39	1·29	1·20	1·02	0·85	0·70
	4·00	1·50	1·47	1·42	1·31	1·21	1·12	0·95	0·78	0·63
	3·00	1·41	1·38	1·33	1·23	1·14	1·05	0·88	0·72	0·58
	2·00	1·25	1·23	1·18	1·09	1·00	0·92	0·75	0·61	0·49
	1·50	1·08	1·06	1·02	0·93	0·85	0·77	0·62	0·50	0·40
16	4·00	1·39	1·35	1·29	1·18	1·08	0·99	0·81	0·65	0·50
	2·67	1·30	1·27	1·22	1·11	1·02	0·93	0·76	0·60	0·47
	2·00	1·21	1·18	1·13	1·04	0·95	0·86	0·70	0·55	0·43
	1·33	1·07	1·05	1·01	0·92	0·83	0·75	0·59	0·45	0·36
	1·00	0·94	0·92	0·87	0·78	0·70	0·62	0·49	0·38	0·30
12	2·00	1·17	1·14	1·09	0·98	0·89	0·81	0·65	0·50	0·37
	1·50	1·10	1·07	1·02	0·93	0·84	0·76	0·60	0·46	0·34
	1·00	0·96	0·94	0·90	0·81	0·72	0·64	0·49	0·38	0·29
	0·75	0·86	0·84	0·79	0·70	0·62	0·55	0·42	0·33	0·25
8	1·25	1·00	0·97	0·92	0·82	0·73	0·65	0·49	0·35	0·27
Howitzers.										
22c.	2·00	0·72	0·70	0·66	0·57	0·49	0·42	0·33	0·27	0·23
	1·50	0·59	0·57	0·53	0·46	0·40	0·35	0·28	0·24	0·21
	1·00	0·41	0·39	0·36	0·32	0·29	0·26	0·22	0·20	0·19
	0·50	0·23	0·22	0·21	0·21	0·19	0·18	0·17	0·16	0·15
16c.	1·50	0·84	0·81	0·77	0·68	0·60	0·52	0·38	0·30	0·25
	1·00	0·70	0·68	0·64	0·55	0·47	0·40	0·29	0·23	0·20
	0·75	0·58	0·56	0·52	0·44	0·37	0·32	0·25	0·21	0·18
15c.	1·00	0·70	0·68	0·64	0·55	0·46	0·38	0·26	0·20	0·16
	0·50	0·48	0·46	0·42	0·34	0·28	0·24	0·19	0·16	0·13
12c.	0·27	0·38	0·36	0·32	0·26	0·21	0·18	0·15	0·12	0·10
Balls.										
Wall-pieces.	0·010	0·085	0·080	0·065	0·045	0·027	0·018	0·008		
	0·008	0·090	0·085	0·075	0·057	0·045	0·035	0·025		

For diameter of shot and charges, in English, see former Table.

Multipliers for the following Woods.

Beech, ash	1·0
Elm	1·3
Fir	1·8
Poplar	2·0

In oak, the fibres laterally separated by shot immediately close, leaving scarcely an opening; but the rent is often 2 yards long, and the splinters are thrown to the distance of from 12 to 15 metres.

In fir, all the fibres are completely broken, but the only effect produced is the void.

VARIOUS NOTES.

1. A 24-pr. shot at 175 paces, 10 lbs. charge, went through two rows of baulks with 2 feet 9 inches of rammed earth between them, and penetrated 6 to 12 inches into a wall behind.
2. An Austrian 24-pr. shot, with the ordinary charge, passed through a soft wood wall, cramped with iron, 9 feet thick. In a mass of 12½ feet thick, the pene-

tration was from $9\frac{1}{2}$ to 10 feet; and with a charge of $9\frac{3}{4}$ lbs., $10\frac{1}{3}$ feet deep. A $5\frac{3}{4}''$ shell from a 24-pr. gun, with a charge of $4\frac{1}{2}$ lbs., entered $2\frac{1}{3}$ feet.

3. Experiment in New York Harbour, in 1814:

Penetration in a Target of White Oak Timber 5 *feet thick.*

Gun.	Charge.	Distance.	Penetration.	Remarks.
	lbs.	yards.	inches.	
32-pr.	11	100	60	shot wrapped with leather
Do.	11	150	54	to destroy windage.

4. Two oak walls, 13 feet high, 27 inches thick, and 50 feet apart, were battered at 800 paces with 9-inch shells. All passed through the first, and some reached the heart of the second wall, and bursting, ripped off the lining of the neighbouring portions, making rents of 4 to 5 feet long on both sides of the wall.
5. Effect on covered Batteries, (Dublin Note.)
   a. Battery $16' \times 10'$ in the clear—joists 4 feet from centre to centre—bearing between sills 10 feet—plank $12'' \times 6''$, laid flat, covered with clay, a layer of fascines, and 3 feet of earth,—received at 600 paces—
   One 11-inch shell and 2 of $6\frac{1}{2}''$ at 60° elevation } without serious injury.
   One 11-inch „ and 2 of „ at 45° „
   b. Covered Mortar Battery in 1822.—Sills, joists, and covering baulks, $12' \times 12'$—stanchions 4′ 8″ apart—joists same distance—9 feet wide in clear, having an earth covering of 5 feet.
   Three 11-inch shells, with 54 lbs. bursting charge, were buried 3 feet; nearly all the joists were broken, but the covering baulks were not injured.
   An 11-inch shell (5 lbs. charge), laid on the earth covering, shattered a covering baulk, and made a crater of 9 inches diameter, but did not damage the joist. Shells with 3 or 4 lbs. did not damage the baulk.
   The stanchions were lined with 3-inch plank, and when three 11-inch shells, with 5 lbs. charge, were burst within the battery, the supports were so crippled as to be unequal to bear the weight above. With 3 or 4 lbs. the damage was very great.
   c. At Antwerp, in 1832, a covered mortar battery stood proof that was struck with several shells—length 18 feet, breadth 12 feet; having five stanchions in the length of $16'' \times 8''$—with 8-inch framing—covering beams, spars of $6'' \times 7''$; then three layers of fascines, and 3 to 4 feet of earth.
6. In Silesia, in 1810, a shell of 6 p. 1 lig. 6 ps., fired from a howitzer at 330 metres, with a charge of $2\frac{1}{2}$ lbs., against a blockhouse $33\frac{1}{2}$ feet long, $19\frac{3}{4}$ feet wide, and $6\frac{3}{4}$ ft. high, penetrated the wall, and filled the interior with smoke, insupportable for six minutes, though the door and loopholes were open: shell loaded with 23 oz.
7. In 1778, a blockhouse at Schweidelsdorf was twice attacked without success: 2 guns and 1 howitzer were brought against it,—the first had little effect, but the howitzer set it on fire.
8. Blindages at Ciudad Rodrigo, when occupied by the French, placed against the interior wall of ramparts, or other substantial walls; formed of oak, 18 feet long, 8 inches square, 20 to 22 inches from centre to centre, placed on a sill 6 feet from the wall, their heads let into the wall; covered with 3-inch elm plank: a few of the blindages were injured, but none burst into by shells.
6. At the attack of Dresden, in 1813, by the Allies, two redoubts on the left bank of the Elbe, in advance of the stockade covering that part of the city, were

carried; but the stockade, (apparently constructed of unsquared wood, trunks of trees,) though partially injured, was nowhere breached by their artillery. (Rogniat.)

Effects of Shot and Shells against Shipping.

1st. Results of practice at the 'Prince George,' to try and compare the penetration of single shot from H. M. S. 'Excellent,' in October, 1838.—Portsmouth Harbour. Distance 1200 yards.

18-pr.	6 lbs.	charge;	penetration	= $25\frac{1}{2}$	inches average.
24-pr. of 9 feet 6 inches, .	8 lbs.	„	„	= 30	„
32-pr. of 7 feet 6 inches, .	6 lbs.	„	„	= 30	„
32-pr. of 9 feet, ...	6 lbs.	„	„	= 30	„
32-pr. of 9 feet 6 inches, .	10 lbs. 11 oz.		„	= 34	„
68-pr. of 9 feet, or 8-inch gun,	12 lbs.	„	„	= 35	„
„	10 lbs.	„	„	= 35	„
68-pr. carronade of 5 ft. 4 inches, ...	$5\frac{1}{2}$ lbs.	„	„	= 30	„

Mem.—It is impossible to trace *with accuracy* the penetration of shot in the sides of a vessel, but it appears to increase with the weight of the shot. The destructive effects of the larger calibres, the 8-inch, must exceed those of less size.

2nd. Results of practice with live shells against the 'Prince George,' from H. M. S. 'Excellent,' moored at 1200 yards, in November, 1838:

Calibre.	Weight.	Length.	Charge.	Elevation.	Penetration.
68	65 cwt.	9 feet	8 lbs.	$3\frac{1}{8}°$	= 35 mean.
„	„	„	10 lbs.	$2\frac{7}{8}$	= 31 nearly.
„	„	„	12 lbs.	$2\frac{3}{4}$	= 28 one round only.
32-pr.	40 cwt.	7′ 6″	6 lbs.	$2\frac{7}{8}$	= $21\frac{1}{2}$ mean.
„	41 „	8 feet	6 lbs.	$2\frac{3}{4}$	= 28

Of 16 rounds from the 68-pr., 9 exploded in the vessel.
Of 14 „ „ 32-pr., 5 „
Cases selected. 68-pr., or 8-inch gun.

Round 2 penetrated 18 inches in good wood through the ship's side, close to the after part; exploded instantly: the pieces of the shell tore down the cabin bulk-heads, which made an immense number of splinters; a piece of the shell cut in two an iron saddle 3 inches in diameter.

Round 4 penetrated through the ship's side at the orlop deck, in good wood, 28 inches; cut off the foot of a strong rider, 24 inches in thickness, completely shattering the remaining part of the rider, and drew out three large copper bolts from the ship's side; exploded and cut through a plank in the deck, made several large splinters, thrown to a distance of 20 to 30 feet, and pieces of the shell were found in several parts of the orlop.

Round 7 tore out the whole of the lower port-sill from aft, 24 inches thick, and all sound wood; crossed the deck and struck off the lower part of a solid oak knee, 16 inches thick, and shattered the remaining part of the knee 7 feet in length, rebounded from thence on the deck, tore up two planks, exploded and tore up all the cabin bulk-heads left standing after round 2.

Round 9 penetrated through the ship's side into the orlop deck, in fair wood, 28 inches; exploded, cut a strong oak knee, 15 inches thick, into two parts, struck and shattered a strong knee adjoining, sending seven large splinters, torn off the knees, on the opposite side of the deck. Fuze and pieces of shell scattered in various directions in the orlop.

Round 12.—32-pr. of 6′ 6″, 32 cwt., 5 lbs. charge, penetrated the ship's side below the water 13 inches, in good wood, and lodged behind a rider: the shell did not explode, but made an opening in the side, into which the water rushed with force, and in such a position that the carpenters present said it would have been impossible to have plugged or stopped the leak.

Round 13.—32-pr. of 7′ 6″, 40 cwt., 6 lbs. charge, penetrated at a port timber, in good wood, 2 feet thick; exploded instantly, blew out a large piece of the port timber, making several splinters: the aperture made with this shell was very great.

Previous to the practice from H. M. S. 'Excellent,' in 1824, experiments were made at Brest with Paixhan's guns against an 80-gun ship, the 'Pacificateur:' the results in both cases were similar; and the Committee of French Officers gave their opinion, officially, that no vessel whatever could hold out against a battery so armed at a distance of 300 to 500 toises. They also remarked that the risk of fire in a ship equipped for service would be very great, owing to the large quantity of cordage, &c., and the removals of ammunition in action.

In 1845 a series of experiments was made at Portsmouth from H. M. S. 'Excellent,' against the 'Swiftsure,' at the distance of 1443 yards, with results favourable to their application. In several instances the shells exploded on striking the side of the vessel, making breaches which, on or below the water-line, could not have been securely stopped at sea. Of those shells two struck within a few feet of each other, making a breach of upwards of 11 feet in length, and varying in breadth from $2\frac{1}{2}$ to 4, independently of greatly damaging and splintering the timbers.

The extreme range of shot fired *en ricochet*, full charge, with $1\frac{1}{2}°$ to $2°$ elevation on smooth water, is nearly equal to that obtained from the same gun fired at $5°$ elevation.

Effects of Red-hot Shot.

The use of shells will supersede in a great measure that of red-hot shot,—still the latter may be occasionally of great service. The fuze for the shell is sufficient for a range of 2400 yards, but the red-hot shot will have effect at the extreme length of its range. After striking water several times, the shot would still set the wood on fire. A temperature of 800° (barely dull-red heat) will suffice to inflame wood.

On the expedition against New Orleans, 1814–15, an American schooner was set on fire by a battery of field-guns (6 prs. or 9 prs.) after a few rounds, and blew up.

The actual effect of red-hot shot on the floating batteries at the siege of Gibraltar is not sufficiently satisfactory; and it is alleged that their danger would not have been great, had D'Arçon been allowed time to complete them according to his original plan.*

It is stated in documents procured at Madrid by the present Earl of Cathcart, during the Peninsular War, that the floating batteries were set on fire by the Spaniards themselves, to prevent their falling into our hands; and that but one instance occurred in which the red-hot shot had taken full effect.

Effects of Shot on Cast Iron.

This material cannot be used when exposed to shot or shells without great danger to the defender, and from its own qualities is but very ill adapted to works of defence.

1st. Shot fired with a velocity of 140 metres per second, split into many pieces, and scatter splinters with some force.

2nd. A mass of cast iron, 1 metre square and ·30 metre thick, was split by shot fired with small velocity.

3rd. A platform (châssis d'affût de côte) of greater dimensions and weight than usual was broken in several places by a single shot of 8 lbs. with a velocity of 150 metres per second.

* See D'Arçon's explanation of the cause of the failure.

Effects of Shot on Lead.

In penetrating a mass of lead with a velocity of 225 metres, shot break, but make no external splinters. The opening made is sufficiently large to allow an easy withdrawal of the shot.

Penetration in a snow parapet 20 *feet thick, slightly rammed, and with some fragments of ice, on the St. Lawrence, opposite Montreal, in February,* 1840.
Service Charges.

Nature of Shot.	Range.	Greatest penetration.	REMARKS.
	yards.	ft. in.	
9-pr.	600	8 0	A 9-pr. shot striking against a fragment of ice was broken into four pieces.
6-pr.	600	4 6	
Musket-ball	50	3 0	
"	75	2 7	
"	100	2 4	

Effects of Musketry.

1. The French musket-ball, from a distance of 22 metres, penetrates a gabion filled with sap fascines ·50 metre, and that of the *fusil de rempart*, ·60. A rolling gabion filled with fascines is proof against the *fusil de rempart* at 15 metres.

2. The penetration of musket-balls into woolsacks is double that into settled ground.

3. Musket-proof shutters,—

Of deal, 3 inches thick, covered on one side with rolled iron $\frac{1}{8}$ inch, are proof against a cavalry carbine at 10 to 14 yards; but with double cartridge the ball passed through.

With iron of $\frac{1}{8}$ inch on both sides, the shutter was proof against a double charge.

In trials with the ordinary firelock, rifle, and carbine, the latter, with double charge, gave the greatest penetration.

4. In battle, it has been calculated that five rounds per 1000 take effect; and of artillery, 10 in 100 rounds.

Penetration of Leaden Balls—Experiments made at West Point (United States) in 1837.
Penetration in seasoned White Oak.

Arm.	Charge.	Distances in Yards.							REMARKS.
		3½	9	50	100	150	200	300	
	grains.	in.	in.	in.	in.	in.	in.	in.	
Musket	134	2·00	1·60	1·43	1·	0·66	0·55	0*	* 1 ball in 10 imbedded.
Musket	125	1·60	..	..	..	..	..	..	
Musket	90	1·60	..	..	..	..	..	..	
Common rifle	92	2·10	1·80	1·43	0·94	0·65	0·29	0†	† Indentation 0·2 inch.
Hall's rifle	70	1·12	1·70	0·63	0·53	0·40	0·0‡	..	‡ 2 balls in 10 imbedded.

The musket, fired at 9 yards' distance, with a charge of 134 grains, 1 ball, and 3 buck-shot, gave for the ball a penetration of 1·15; buck-shot, 0·41 inch.

ADDITIONAL REMARKS.§

Breaching.—Under the article 'Breach,' the Metz experiments have been already referred to; but as they are the most complete experiments directed to that object

§ By Lieut.-Col. Portlock, R. E., F. R. S.

on record, it seems desirable that the results should be stated in such detail as will permit of their application as a datum of comparison for the operation of breaching generally.

The mode of breaching which the Metz Committee deduce from the experiments ought to be known and considered in a comparison with any other results.

In practice before an Enemy, the difficulties of following out closely definite principles may be great; but the object ought at least to be to approximate to them.

1. The breadth of the ditch and covert-way, the height of the counterscarp and crest of the covert-way, the height of the scarp, and thickness of the parapet, should be carefully ascertained.

From these data, reduced to a profile, it will be easy to determine the height of the horizontal section of the intended breach, in such a manner that the débris of the scarp wall may be sufficient to form a ramp of 1 to 2 slope. The height ought not to be less than a third of the scarp, that the débris may not be in the way, and at least equal to the thickness of the revetment at the line of section.

2. The elevation or depression of the gun, and the directions of each at the first series of discharges, should be so marked as to insure the shot striking the same points at each corresponding series. Beginning from the left and proceeding to the right, or *vice versâ*, each successive shot should strike the wall with 16-prs. at 1 metre, and with 24-prs. at $1^{m}\cdot25$ or $1^{m}\cdot50$ from the preceding one, through the whole line of section; and on the return from the right to the left, the shots should bisect the intervals between those of the preceding series.

It is essential that the section should progress equally throughout its whole length, and be continued only until the appearance of earth indicates that the revetment has been cut through, as the running out of much earth would cause the falling masonry to encumber the surface.

3. The vertical sections should be in number one for each gun, the distance between them never exceeding 10 metres, and, if possible, being less, so that the masonry may not be supported by more than one, or, at the most, two counterforts. The vertical section should begin by shots at short distances of $0^{m}\cdot3$, until the wall is well cut through at the base, and then the distances should be 1^{m}, proceeding first from the base upwards. Great care is necessary to keep the progressive advance of all the sections equal, as the oblique fall of part of the masonry from an inequality of support would seriously encumber the breach.

4. The wall having fallen, and the visible portions of the counterscarp having been destroyed, it is desirable to change two of the guns for 8-inch howitzers, to complete the destruction of the parapet by shells.

Time of Breaching.—1st, with 16-pounders and 8-inch howitzers.

Guns or Howitzers.	Shot or Shells.	Time. Opening Revetment.	Destroying Counterforts.	Destroying Parapet.	Changing 2 guns for howitzers.	Total.	REMARKS.
		h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	
4 guns	270 shot	5 37 5	..	..	..		Distance from muzzle of gun to scarp 21·40 metres; excavation 22·75 metres wide, 4 metres high, 2·2 metres thick at base, and 1·42 metre at cordon.
..	36 shot	..	0 50 0	..	..		
2 howitz. & 2 guns	40 shells	..	..	1 0 0	..		
..	..	..	..	..	2 0 0		Total excavation 164·91 metres. The average rate of firing was 5′ per shot.
						9 27 3 or 9½ hours.	The shells were partly fired experimentally, to ascertain the proper charges.

The work of the guns was 1^m cube in 2′ 3″. After the firing of round shot had ceased, the breach, though still steep at the crest, was ascended by 30 gunners in line at a trot.

The shells perfected the breach,—those fired from the guns produced little effect, as they broke against the sand when fired with a charge sufficient to insure penetration.

With charges of 1^k to $1^k{\cdot}50$, the shells from the howitzers penetrated 1^m, and being loaded with 2^k, produced by explosion entonnoirs which rapidly brought down the parapet.

To insure success, the fuzes must be filled with composition, and sunk well into the eye of the shell.

2nd.—Time with 24-pounders and 8-inch howitzers.

Guns or Howitzers.	Shot or Shells.	Time. Opening Revetment.	Destroying Counterforts.	Destroying Parapet.	Changing 2 guns for howitzers.	Total.	Remarks.
		h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	
4 guns	195 shot	4 3 45	..	..	..		Distance from muzzle of gun to scarp 31·9 metres. Excavation 21·66 metres wide, 4 metres high, 1·81 metre mean thickness. Total excavation 156·81 m.
..	38 shot	..	0 50 0	..	..		
2 8-in. howitz.	18 shells*	..	..	1 0 0	..		
..	..	..	..	..	2 0 0		* These were shells from the howitzers alone. The shells from the 24-prs. were ineffective, as they could not be fired with a charge sufficient to insure penetration.
						7 53 45 or 8 hours.	

The work of the guns was 1^m cube in 1′ 33″. As with the 16-prs., the breach, though steep at its crest, was practicable at the close of the gun-firing. The number of shots fired, and the times of effecting the breach, being nearly in an inverse proportion to the weight of the shot, viz. 22 to 16, the total weight of metal and powder fired will be nearly the same; and, in consequence, the advantages of the 24-prs. over the 16-prs. will be that of diminished time with an increased distance,—the 16-prs. having been $21^m{\cdot}40$, and the 24-prs. $31^m{\cdot}9$ from the scarp.

These experiments, affording an accurate estimate of the possible working power of guns and howitzers when used under proper conditions, the more those conditions are departed from, whether from deficient skill or unfavourable circumstances, the less will be the effect produced, and the greater the time occupied.

The elements of efficiency are, the force of penetration of the projectile when it arrives at the wall, and the accuracy with which it is directed to a particular point or line.

The first of these will in round shot diminish with the distance of the battery (as the charge continues the same), but in shells discharged from howitzers it may be preserved undiminished by augmenting the charge, originally reduced to keep the shells from breaking against the parapet.

The amount of diminution from increased distance may be estimated either from the Table of Terminal Velocities, calculated by Colonel Piobert, or by direct reference to the Tables of Penetration given in this article.

Referring to that of penetration in masonry,

at 25 metres	a 24-pr. shot, with a charge of $\frac{1}{2}$, penetrates	0·650 metre.
300	” ” ” ”	0·530
		0·120

therefore in 275 metres, or 300 yards nearly, the penetration has diminished nearly $\frac{1}{5}$th.

The penetration will therefore at the distances of 27 and 328 yards be respectively as 5 to 4; and as the diameter of the base of the conical portion of the excavation made by the shot varies also with the penetration, the actual effect of the firing, in making either the horizontal or vertical sections at those distances, will be as 5^2 to 4^2, or 25 to 16:* hence the time of effecting the first portion of the breach will be augmented more than one-half by the increase of distance alone.

With the French 16-prs., fired with a charge of $\frac{1}{2}$, the results will be as follow:

at 25 metres, or 27 yards, the penetration is			. . . .	0·570
300 ,,	327 ,,	,,	. . . .	0·445
therefore in 275 metres, or 300 yards, the penetration has diminished				0·125

or between $\frac{1}{4}$ and $\frac{1}{5}$; and the actual effects on making the sections will be between the proportions 25 to 16, or 16 to 9; and the time will be increased between $\frac{1}{2}$ and $\frac{2}{3}$ by increased distance.

The second element, or the comparative accuracy of firing at different distances, requires yet to be based on experiments.

In the 'Aide-Mémoire d'Artillerie,' 1844, page 412, it is stated—"The number of shots striking a target 1 metre square at 600 metres, or 654 yards, is in 100—for 24-prs. 7; for 16-prs. 6; for 12-prs. 5; for 8-inch howitzers 4; for 6-inch howitzers 5:" from which it is evident how greatly the efficiency of breach firing must be diminished by increased distance, the shots striking over a large surface, and breaking up the wall into small fragments, rather than bringing it down in masses.

It was doubtless this system of pounding the wall which rendered the earlier formation of breaches so tedious; and the more irregular the firing, the nearer will the modern approach to the ancient practice in character.

At 300 metres, or 327 yards, if one-half of the shot, or 50 per cent., and one-third of the shells, be supposed effective (and these are probably very high proportions), the following would be the possible time of effecting breaches, under the most favourable circumstances.

With French 24-prs.—One gun to 5·41 metres or 5·9 yards running of scarp.

Opening revetment at short distances.	Increase for diminished penetration.	Increase for diminished accuracy of fire.	Changing guns for howitzers.	Destroying parapet at short distances.	Increase for diminished accuracy of fire.	Total.
$4^h\ 53'\ 45''$	$2^h\ 26'\ 52\frac{1}{2}''$	$7^h\ 20'\ 37\frac{1}{2}''$	$2^h\ 0'\ 0''$	$1^h\ 0'\ 0''$	$2^h\ 0'\ 0''$	$19^h 41' 15''$

With French† 16-prs.—One gun to 5·69 metres or 6·20 yards running of scarp.

Opening revetment at short distances.	Increase for diminished penetration.	Increase for diminished accuracy of fire.	Changing guns for howitzers.	Destroying parapet at short distances.	Increase for diminished accuracy of fire.	Total.
$6^h\ 27'\ 5''$	$3^h\ 13'\ 32\frac{1}{2}''$	$9^h\ 40'\ 37\frac{1}{2}''$	$2^h\ 0'\ 0''$	$1^h\ 0'\ 0''$	$2^h\ 0'\ 0''$	$24^h 21' 15''$

* If the fall of the masonry depended exactly on the total effect of the shot *in all directions*, the ratio would be as the cubes of the penetrations. It has been shown that with guns of different calibres the times are nearly inversely as the weights of the shot, or with 16 and 24-prs. as 22 to 16. These numbers, if examined, will be found more nearly proportionate to the squares than to the cubes of the penetrations; and in like manner with guns of equal calibre, but at different distances, the times will vary in a proportion nearly corresponding to the squares of the penetrations.

† The French 16-pr. shot being equivalent to a shot of $17\frac{3}{8}$ lbs. English, all the results of that description of gun may be applied to the English 18-prs.

Before an Enemy, the difficulties and casualties attendant upon the opposing fire must greatly augment these numbers, which are normal, or depending only on the qualities of the arm used: it is probable even that at very short ranges the time would be trebled from such considerations, and at 300 yards doubled; so that it may be fairly stated that breaches formed by guns and howitzers in the manner adopted at Metz, and with a similar proportion of guns to the extent of scarp to be destroyed, cannot be expected to be formed in less than the following times:

At 25 metres, or 27 yards.		At 300 metres, or 327 yards.	
With 24-prs. French = 26½ lbs. English.	With 16-prs. French = 17½ lbs. English.	With 24-prs. French = 26½ lbs. English.	With 16-prs. French = 17½ lbs. English.
23^h 41′ 15″	28^h 21′ 9″	39^h 22′ 30″	48^h 42′ 30″

These numbers may, however, when there is convenient space and an abundant armament, be diminished by the use of more guns, as appears to have been the case at Ciudad Rodrigo, where the proportion was one gun to 5 feet of scarp, instead of one to 18½, as at Metz; and this will account for the comparative rapidity of forming the breach in that siege at an increased distance, independently of the inferiority of the masonry.

If these principles be applied to still further increased distances and to diminished charges, as in Ricochet Firing, it will be evident that the destruction of masonry traverses must be tedious, the force of penetration being diminished to about a third, and the inaccuracy of firing augmented in a large proportion.

Earthen traverses will be best destroyed by shells from howitzers; but, although the force of penetration will not vary so much with this arm, the uncertainty of fire will be augmented in a still greater ratio.

These considerations may suggest some useful remarks both as regards Ricochet Firing, and the construction and arrangement of Traverses, but they can be best noticed under their respective heads.

MEMORANDUM ON PENETRATION OF PROJECTILES.

An American 32-pr. at Fort Monro, in 1836, at 880 yards, fired with one-quarter the weight of shot, at 1° of elevation, penetrated as follows:

In hard brick	15·25 inches.
„ Potomac freestone	12·0 „
„ dressed granite	3·5 „

Nearly all the shot were broken, even at the charge of ¼, and the fracture was generally in meridional planes, the pole of which is the point which strikes first. The effect of shells fired horizontally against masonry was very small. An 8-inch sea howitzer, with a charge of 6 lbs. at an elevation of 1°·35, and at 880 yards range, penetrated

In hard brick	8·5 inches.
„ Potomac freestone	4·5 „
„ dressed granite	1·0 „

N.B. These experiments were communicated to Colonel Moody, R.E., by a Committee of Ordnance Officers in the Service of the United States.

The above information was kindly given me by General Cardew, R.E.

E. T. WILFORD.

Note.—The following facts were elicited at the siege of Mooltan in 1848-9:

Major Siddons, of the Bengal Engineers, in his account of the siege of Mooltan, given in the first volume of 'Corps Papers,' states—"It is impossible to overrate the services rendered by the 8-inch and 10-inch howitzers. The walls are mostly of mud; and it so happened that the part selected for the breach was very defective,—a mere facing over the old wall. In this the 24-pr. shot brought down large masses; but where the work was sound, the shot buried themselves, whereas the shells penetrated, and thus acted as small mines. Against a mud fort a howitzer must therefore be considered far preferable to a gun, though of course the latter would be more effective against a wall built of stonework."—*Editors.*

Plate I. PETARD.*—The petard, which formerly was part of the equipment of an army in the field, for the purpose of bursting open gates, has of late years been in disuse, and bags or cases of powder have been substituted for it.

The petard was of brass, and cast in a bell shape. It was fastened to a bed of elm plank, 3½ inches thick, having on the reverse, or under-side, a wrought-iron plate, one-quarter of an inch in thickness. In the breech there was an aperture for the fuze, which was connected to the petard by means of a brass holder.

Four men were employed to carry the petard, and rings were placed at the angles of the bed for this purpose. A fifth ring was fastened to the upper side of the bed, as a means of connecting it to the gate intended to be destroyed, into which a hook was screwed to support it. The bed of the petard was still more firmly secured to the gate by means of screws from 6 to 8 inches long.

Two legs, or struts, were attached to the petard bed; they were between 4 and 5 feet long, and 4 inches in diameter at the bottom, or thicker end.

	Cwt.	qrs.	lbs.
The weight of the petard, with its fuze and bed, was	2	2	12
" legs	0	1	16
" screw-hooks	0	0	5
Total weight	3	0	5

The objection to the petard was, that on being fired with the full Service charge of 11 lbs. of powder, it was liable to burst, and the men of the party using it were exposed to injury from the splinters.† Bags of powder are not open to the same

* By Colonel Sir Frederick Smith, K.H., R.E., F.R.S.

† Major-General Sir Charles Pasley, K.C.B. (then Colonel Pasley), in testing the relative efficiency (in the year 1825) of the petard and the powder-bag, had recourse to the following experiments:

Two pairs of palisade gates were formed, to one of which a bag containing 50 lbs. of gunpowder was attached, and to the other the petard loaded with the usual Service charge of 11 lbs. of gunpowder.

The bag was fastened by a hook to the centre of the gate. The explosion fully succeeded in blowing open the gates; that half to which the bag was suspended was thrown completely back: the effect upon the other half would have been similar, had not the bottom of the gate struck against the ground, which stopped it; but the gates were thrown entirely open, and the result was all that could have been desired.

The petard was suspended by a bolt from the top of the gates, so as to bring the centre of the petard opposite to that part where the iron swing bar was fastened, and the two legs were placed so as to ease the weight from the bolt. The fuze was lighted, and the charge exploded, bursting the petard into several pieces, while the effect was only that of breaking a hole through the gates, of about 4 feet wide, for they were not even thrown open, and that half of the gate which was bolted at the bottom was not forced from its fastenings.

Parts of the petard bed were thrown to a considerable distance. One piece of the petard, weighing 11¼ lbs., was thrown a distance of 60 yards, and a part of the bed was blown to the distance of 126 yards; several smaller parts were also found within that radius. The two legs were thrown 20

objection, and they have the advantage of being more easily procured, and much more portable.

Bags of powder may be successfully used either to blow open gates or to form breaches in stockades, or even in thin enclosure walls; and the efficacy of this means of overcoming such defences will be best understood from the records of some experiments conducted at the Royal Engineer Establishment at Chatham, with a view to ascertain the requisite charges, and the best mode of applying them under various circumstances.

Report of an Experiment in blowing open a pair of palisade gates with a bag of powder.

Experiment No. 1.

The gates used for this experiment were of oak (each gate being 8 feet high by 5 feet wide). They were of triangular scantling out of 4-inch oak, cut diagonally in halves. Two posts, of about 10 inches in diameter and 15 feet long, were planted 3 feet deep in the ground, and the gates were connected with them by means of three pieces of stout scantling, placed across at the top, bottom, and centre, and spiked securely to the posts, as well as to the palisades of the gates. A strong strut was also fixed against each post, and another against the bar, which extended across the centre of the gates.

The charge used on this occasion was 50 ℔s. of powder. It was contained in a bushel sand-bag, tarred and sanded over; a loop of half-inch rope was attached, for suspending the bag. On one side of the bag, near the bottom, a small collar of stout canvas was sewn, so as to stand out about 6 inches, as a precaution against the fire communicating to the charge before the fuze should be burnt out. A piece of Bickford's fuze 2 feet in length was used in firing the charge, one end being pushed through the collar into a hole made in the sand-bag.

By the explosion both gates were blown open and destroyed, and the posts were knocked down. Some of the pieces of the gates were thrown upwards of 150 yards to the rear, and several huts in the immediate neighbourhood were partly unroofed.*

Report of an Experiment in breaching stockades with bags of gunpowder.

On the 16th April, 1840, a preliminary trial was made of a bag containing 60 ℔s. of powder, laid on the ground, close against two beams of African oak (old ship-timber obtained from Her Majesty's Dockyard), the scantlings of which were 13 inches by 11 inches, and 11 inches by 8 inches. The beams were sunk 3 feet in the ground, and were 3½ inches apart. A piece of Bickford's fuze 4 feet long was attached to the bag. The explosion blew both timbers out of the ground, shattering one and splitting the other.

On the 21st April, 1840, a strong stockade 21 feet in length, composed chiefly of English and African oak obtained from the Dockyard, was erected within a few feet of high-water mark, on the glacis in front of the left bastion of the works at St. Mary's Creek.

A trench 21 feet long, 2 feet wide, and 3 feet deep, having been made, the timbers were planted in it at intervals, and the soil, a stiff clay, was well rammed about them.

Five bags covered with water-proof composition, and each containing 60 ℔s. of gunpowder, were prepared, and two of them had a Bickford's fuze 3 feet long attached.

Experiment No. 2. Plate II.

On the 25th April, 1840, an Officer carrying a slow-match, with five men

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feet to the right and left of the gates, and a great part of the iron plate from the bottom of the bed was projected several yards.

The thickness of metal of the petard was found to be 1¼ inch at the breach, and 1 inch next to the bed.

* This and the following experiments were tried when the Royal Engineer Establishment was under the direction of Major-General Sir Charles Pasley, K.C.B.

carrying the powder-bags, advanced to the stockade. No. 3 first deposited his bag on the ground close against the middle of the stockade. Nos. 2 and 4 placed theirs on the right and left of No. 3, the ends of the bags touching. The bags Nos. 1 and 5, with fuzes attached, were immediately placed over the centre of and upon the first three bags. All the carriers excepting one, who remained to bring the ends of the fuzes together, retired. The Officer immediately lighted the fuzes. The explosion threw up an immense volume of smoke, with numerous fragments of timbers, some of which went nearly across St. Mary's Creek, a distance of 123 yards. As soon as the smoke dispersed, a most perfect breach, 12 feet wide, became perceptible. The stoutest timbers were shattered to pieces, and a crater was formed the whole length of the breach, 9 feet wide and 3 feet deep.

The stockades adverted to in the following experiments were erected between the years 1842* and 1850, on the practice-ground of the Royal Engineer Establishment, on the left of Chatham Lines; and the timbers, sometimes of oak, and sometimes of fir, were generally 12 feet long, and about 12 inches square in their cross section. They were placed in close contact in a trench 3 feet deep, and they were connected together by one or more ribands firmly spiked to them. After being planted in the ground, the earth that had been excavated in forming the trench was carefully rammed round the timbers, so as to give the construction every possible degree of firmness and solidity.

The charge in each case was placed in contact with the timbers of the stockade, and contained in tarred sand-bags; and, when not stated to the contrary, it was fired by means of Bickford's fuze.

Experiment No. 3. Plate III.

A stockade of about 24 feet in length was constructed, for the purpose of being breached by means of gunpowder, on the 25th October, 1842.

It was composed of Baltic fir, procured from Her Majesty's Dockyard.

The timbers were connected by a riband of English oak, 6 inches square, to which they were firmly spiked at the bottom of the trench.

The charge of gunpowder used to form the breach was 240 lbs., contained in four tarred sand-bags. The bags were placed in two tiers; three on the lower, and one on the upper tier. A piece of ½-inch hose, filled with gunpowder, and 4 feet in length, was fastened to the middle bag of the lower tier for a train, and a piece of portfire 2 inches long was attached to it: a perfect breach, about 12 feet wide, was the result of the explosion.

Experiment No. 4. Plate IV.

This stockade was 22 feet long, and composed of Baltic fir. The timbers were connected together by a riband 6 inches by 4 inches, placed at the bottom of the trench.

The charge consisted of only 60 lbs. of powder, contained in a tarred sand-bag, having 2 feet of Bickford's fuze attached to it.

The powder-bag was placed on the ground, and a bushel bag filled with sand was laid on the top, and one at each end, as tamping: the explosion formed a practicable breach of about 6 feet in width.

In the month of December, 1845, a stockade was constructed about 30 feet in length, and the upright timbers connected together by three ribands; one on the inside near the top, and two near the bottom, of which latter, one was on either side of the uprights: the earth was rammed on both sides of the uprights to the level of the ground.

* When Sir F. Smith had succeeded Sir Chas. Pasley at Chatham as Director.

For the purpose of ascertaining the minimum charge for destroying a stockade of the strength above described, the following experiments were tried on the 15th and 21st January, 1846.

Experiment No. 5.

An attempt to breach was made by firing a charge of 30 lbs. of powder, contained in a bag, and suspended to the stockade opposite to the upper riband, and 3 feet from the north end. The effect was merely to dislodge a few of the timbers from their upright position.

Experiment No. 6.

A second charge of 30 lbs. of powder was next slung on a nail, at a height of 3 feet from the ground, and 6 feet from the north end. On the explosion of this charge, it was found that one timber only was broken through, and a few others slightly shaken.

Experiment No. 7.

A similar charge was placed at the distance of 3 feet from the southern extremity of the stockade, on the ground, and touching the timbers. A crater 2 feet in length, 12 inches in depth, and 15 inches wide, was formed by this explosion, and seven timbers were started, one being broken short off close to the ground.

Experiment No. 8.

A fourth charge of 30 lbs. of powder, also contained in a bag, was laid on the ground at 6 feet from the southern end of the stockade. Two bushel bags of earth were laid upon the bag of powder, and two were placed in front of and in contact with it. On firing the charge, it formed a narrow breach in the stockade by driving two of the piles out of the ground, and breaking another asunder, besides dislodging several of the timbers adjoining.

Experiment No. 9.

A charge of 70 lbs. of powder, and another of 50 lbs., were placed on the ground with an interval of 5 feet between them, and both touching the stockade near the middle of its length. Four bushel sand-bags, filled with earth, were applied as in the preceding experiments, upon and against each charge.

In this instance a spacious breach was made, and some of the piles were thrown upwards of 50 yards from the stockade; and from these experiments it may be concluded, that from 60 to 70 lbs. of powder, properly loaded with bags of earth, will be a sufficient charge for producing a practicable breach in a stockade of this strength. The extent of breach required will of course regulate the number of charges to be used.

Experiment No. 10. Plate V.

6th September, 1846.—Major Marlow, Commanding Royal Engineer in New Zealand, having sent to England drawings and a description of one of the 'Pahs' constructed in that country, by the Chief, Heki, a part of a stockaded work, nearly on that plan, was erected in August, 1846, on the left of Chatham Lines, with a view of ascertaining by experiments the best mode of breaching it by bags of powder.*

The external fence consisted of a frame-work of double posts, 6 inches by 10 inches, firmly spiked together; placed at intervals of 5 feet 3 inches, and connected by two ribands above ground, 12 inches wide and 4 inches thick, and by one riband under ground, of the same dimensions. To the two upper ribands, fascines were fixed, extending to within 2 feet of the ground, to represent the green flax used in the same position in 'Heki's Pah.' †

The second enclosure consisted of oak timbers, also 10 inches square, placed close together, and connected by an underground riband 12 inches wide and 4 inches thick.

The upright timbers in both enclosures were 9 feet above ground, and 3 feet in the ground.

An interior enclosure, or keep, 10 feet 9 inches distant from the last-described, was

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* The deviations are improvements on the rude construction of the New Zealanders.

† See article 'Pah,' vol. ii.

formed of oak timbers, fixed 2 feet 6 inches in the ground, and 9 feet 6 inches out of it. The timbers were 12 inches square, and also placed in close contact; they were united by one riband above ground, and one under ground, each 12 inches wide and 4 inches thick. The communication to the interior of the keep, from the middle enclosure, was formed by means of an underground gallery, 4 feet 6 inches by 3 feet, driven within and parallel to the stockade of the keep, at the distance of about 3 feet 3 inches, as a place of security for the garrison from the fire of the enemy's artillery. The interior and the centre enclosures were loopholed.

The earth was well rammed round the timbers.

Plate V.

On the 4th of October, 1846, the pah was attempted to be breached by the following process: a tarred sand-bag containing 100 lbs. of gunpowder was passed underneath the fascines of the outer enclosure, and lodged in the position marked A, in contact with the stockade G H of the centre enclosure, and two bushel bags filled with earth were placed upon it as shewn in drawing (F).

At the distance of 3 feet 6 inches from this charge, another of 100 lbs. (B) was also placed on the ground, and in contact with the same stockade, but on this charge no sand-bags were placed. The two charges were fired simultaneously, and a practicable breach, of about 8 feet in width, was formed in the outer and centre enclosures, the débris of the one being thrown outwards, and of the other inwards. The inner stockade was not injured: another bag, containing 150 lbs. of powder, was afterwards placed in contact with it, in the position marked C, but it was not weighted with bags of earth. On being fired, a breach was formed of about 6 feet in width.

Experiment No. 11.

1st December, 1846.—It being considered necessary to have further experience in breaching double stockades, another portion of a stronghold similar to 'Heki's Pah' was constructed.

A charge of 120 lbs. of powder, contained in two tarred sand-bags, was lodged against the centre line of timbers. Four bushel bags were filled with common earth, and two of them were placed on the top of the charge, and one at each end.

The result of the explosion was the destruction of about 10 feet of the centre and outer stockade, and pieces of both were thrown upwards of 200 feet from the line in which they had been placed: the timbers of the inner enclosure or keep were merely disturbed from their upright position, but they were not thrown down or broken.

Experiment No. 12.

8th June, 1847.—A double stockade was erected for the purpose of training the Embodied Pensioners (then about to proceed to New Zealand) in the mode of capturing such works, and also to obtain further information on the subject.

This stockade was composed of oak timbers, 13 feet long and averaging 13 inches in thickness and breadth, placed in trenches 4 feet deep, so that 9 feet were above ground.

There was an interval of 4 feet 4 inches between the two lines of stockade.

The timbers of each line were united by two ribands, 12 inches wide and 4 inches thick, of pitch pine plank. The upper riband was placed at the distance of 7 feet from the ground, and the lower one with its upper edge flush with the surface.

The two lines of timber were joined together at their extremities by two cross ribands of the same width and thickness as the longitudinal ribands, to give that degree of general stiffness which would be found in a complete stockade enclosure.

A charge of 200 lbs. of gunpowder, in four bags, was lodged in four layers at the bottom of the outer line of stockade, the lower bag resting on the ground.

Two sand-bags filled with earth were placed on the top of the upper bag of powder, besides two in front of the charge, and one at each end of it, in order to confine the action of the gunpowder as much as possible to the stockade.

A piece of Bickford's fuze 6 feet in length was attached to one end of the central bags, 6 inches of it being inserted within the bag.

The fuze was ignited by slow-match, and the explosion of the whole charge was simultaneous. A breach was formed in both lines of stockade. The width of the opening in the outer line measured 9 feet 6 inches, and that of the inner line about 5 feet 6 inches.

Experiment No. 13. 9th June, 1847.—The double stockade breached this day was formed in the same manner as that destroyed on the 8th June, the only difference being that the interval between the two rows of stockade was in this case 3 feet 5 inches, instead of 4 feet 4 inches.

It being desirable to ascertain whether both lines of stockade might be breached at the same time by 200 ℔s. of powder *without confining the charge with bags of earth*, none were used on this occasion.

The company of Embodied Pensioners for service in New Zealand were practised in advancing to the face of the stockade, covered by sap rollers, having in the rear of the centre sap roller a truck containing the charge of gunpowder.

On reaching the foot of the stockade, the sap rollers remained in their position, and the truck was moved into an interval between two rollers. On tilting up the truck, the bags of powder slipped off and lodged at the foot of the stockade. This was effected without difficulty, and there is every reason to presume that, on actual service, men advancing to lodge the charge might be thus protected against the musketry fire of the garrison, when the situation was favourable to such a proceeding.

By the explosion a breach of 6 feet 6 inches was made in the outer line, and one of 4 feet in the inner line.

Experiment No. 14. 11th August, 1848.—A stockade was erected on the causeway adjoining the ditch of St. Mary's Hornwork.

A breach was effected, sufficient for the passage of about twelve men abreast, by the explosion of two charges of gunpowder, each consisting of 100 ℔s., and separated from each other by an interval of 6 feet. The charges were placed in water-proof bags, and a bag of earth was laid on the top, and one at either end of both charges.

The conclusion to be drawn from the various experiments above described is—

1st. That any single line of stockade, when the timbers do not exceed 14 inches in thickness, may be breached by a charge of 100 ℔s. of powder placed on the ground and in contact with the timbers; and that when bags of earth are placed upon and against a charge, its effect on the stockade will be greatly increased.

2nd. That a double stockade may be breached by one charge of 200 ℔s. of powder lodged against the outer line of timbers, when the interval between the rows does not exceed 3 feet 6 inches.

3rd. That when there is reason to presume that the interval between the rows of timber is much greater than 3 feet 6 inches, the breach in the two lines must be produced by two distinct explosions.

The chief difficulty in all attempts to force an entrance into defensible works of the description under consideration is the placing of the charges without exposing the party employed in this critical operation to great risk.

Even when the attack of a stockade is made at night, it may be presumed that some loss would be sustained by the assailants if they advance to the stockade without having any cover, whatever may be the caution with which they approach it; and therefore, as a security against failure from casualties, it would be desirable to attempt to attach powder-bags at various points of the enclosure.

If the attack be made by day, the mode of approach must be determined by local and other circumstances; probably the show of an escalade, under a heavy fire of musketry and artillery, may enable the Engineers to lodge their powder-bags, &c. at the foot of the stockade; but where circumstances will admit of waiting for the construction of sap rollers, and the ground is favourable for pushing them forward, they may be used as a tolerably safe screen for the assailants.

When a town gate has to be breached, it would be unsafe to depend upon a smaller charge than 200 ℔s. of powder, and it should be weighted with three or more bags of earth, as in all probability the gates would be strengthened by cross-bars and struts. In no case does it seem desirable to suspend the charge above the level of the ground.

Bags of powder may also be used in breaching thin walls of brickwork.

The following experiments were tried at the Royal Engineer Establishment, to ascertain the quantity of powder required to form such a breach, and the best mode of applying the charge for that purpose.

3rd October, 1826.—Experiments were made on two brick walls, each 8 feet long, 5 feet high, and 2 feet 3 inches thick, which had been built in the month of November, 1825, or eleven months previous to the experiments.

Experiment No. 1. To the back of one of these walls, two bags each containing 15 ℔s. of powder were suspended at the height of 12 inches above the ground. These charges, which were 4 feet apart, and equidistant from the centre, were fired simultaneously.

After the explosion, the wall appeared to be considerably injured. Those parts of it immediately opposite to where the charges were placed, were forced out to a distance of 1¼ inch, and presented an appearance similar to what would probably be produced by the blow of a battering-ram.

Experiment No. 2. In the second experiment, two charges each of 30 ℔s. of powder were applied to the back of the other wall, on the level of the surface of the ground, 4 feet apart, and equidistant from the centre. A quantity of earth of about 4 feet 2 inches in thickness was heaped over the charges to create a resistance in the opposite direction of the wall.

The charges were fired simultaneously, and the effect was the complete destruction of the wall.*

Results of Experiments in the demolition by gunpowder of walls built of brickwork and cement, between the years 1848 *and* 1850.

Experiment No. 3. Plate VI. *Wall No.* 1, of 9-inch work, 6 feet high and 6 feet long, with piers 9 inches square at the extremities. The depth of the foundation was 1 foot.

The charges in every case were placed on the ground near the centre of the wall.

The first charge, which was of 6 ℔s. of powder, produced no visible effect.

The second charge was of 7 ℔s., and the explosion cracked the wall at the bottom, very slightly, opposite to the charge.

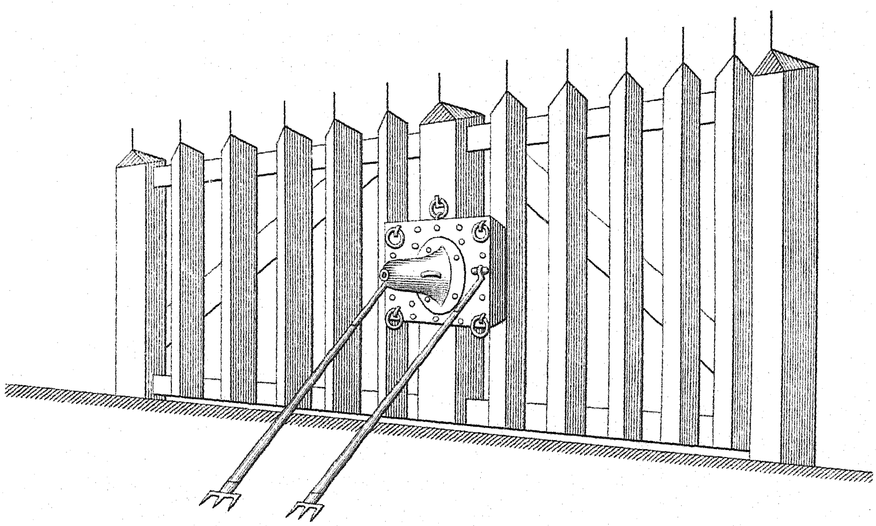
The third charge was of 6 ℔s. of powder, and was weighted with two bushel bags filled with earth. The explosion of this charge utterly demolished the wall.

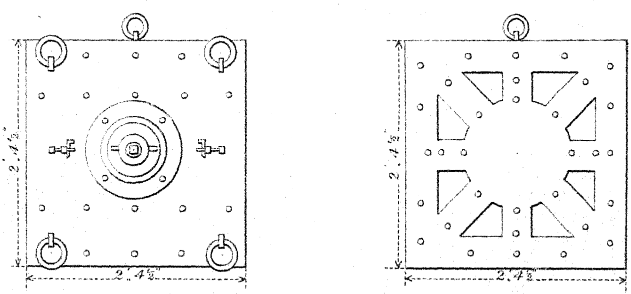
Experiment No. 4. *Wall No.* 2, similar in every respect to Wall No. 1.

The charge of 10 ℔s. of powder was contained in two bags, (one of 6 ℔s. and the other of 4 ℔s.) By the explosion, the wall was fractured at about half its height, besides which a dislocation was produced between the foundation and the remainder

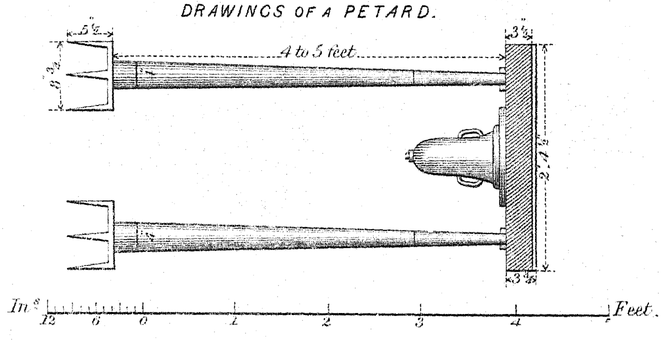
* In the record of this experiment, which appears to have been conducted under the orders of Major-General Sir Charles Pasley, by Lieutenant Renwick, of the Royal Engineers, it is stated that the mortar was "particularly bad," the wall having been built during the continuance of a severe frost.

DRAWING OF A PETARD *as applied to a Palisade Gate.*





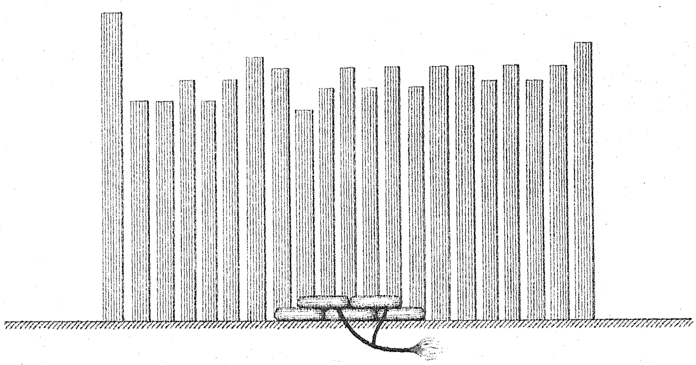
DRAWINGS OF A PETARD.



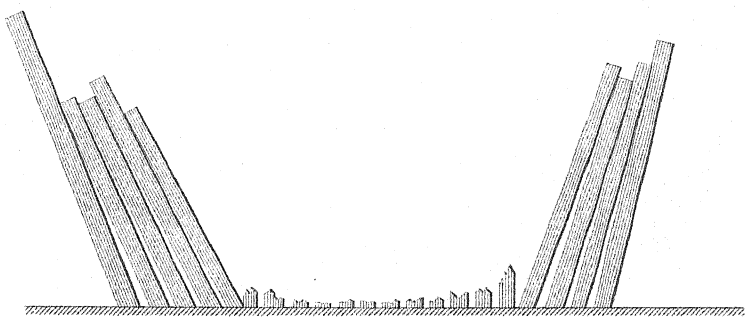
EXPERIMENT Nº 2.

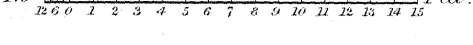
(With a charge of 300 lbs of Powder)

Stockade before the Explosion.



Stockade after the Explosion.



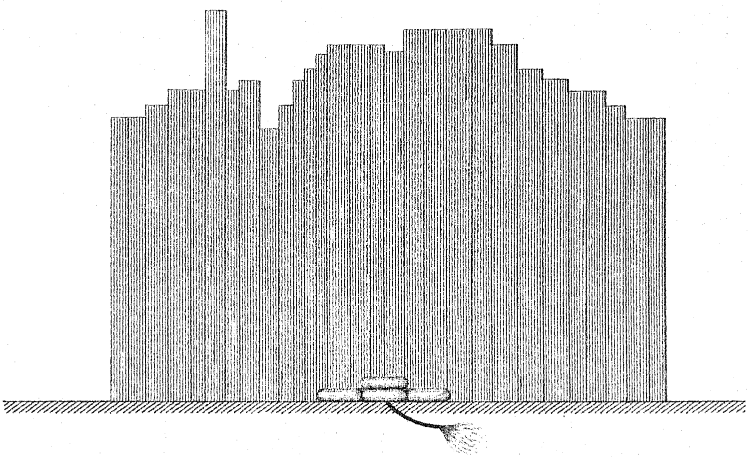


Drawn by A. Callagh…

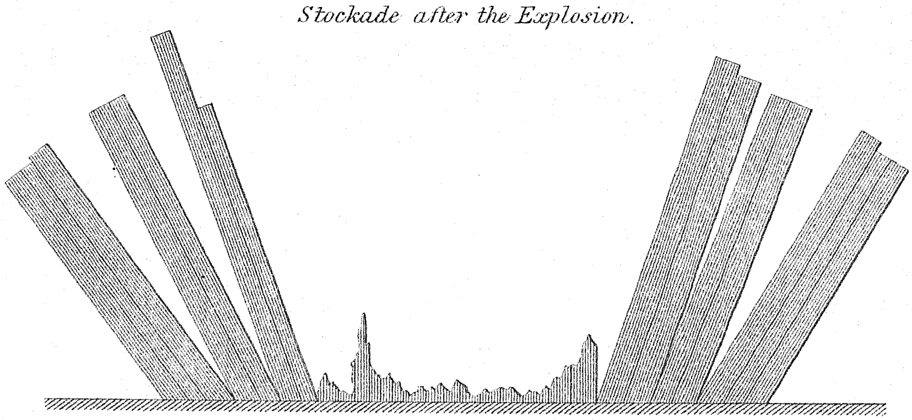
EXPERIMENT No. 3.

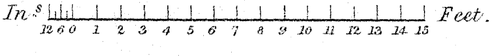
With a Charge of 240 lbs of Gunpowder.

Stockade before the Explosion.



Stockade after the Explosion.



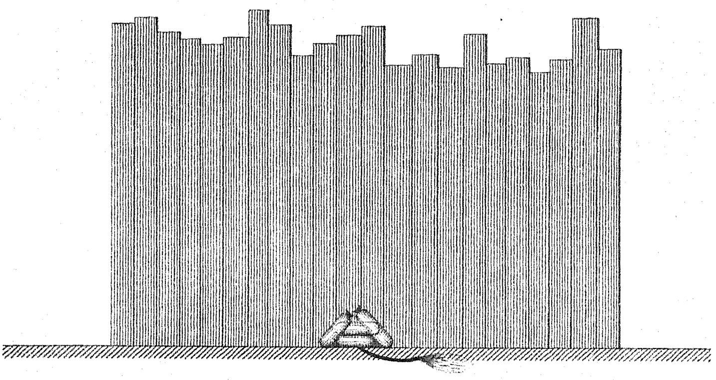


Drawn by A. Callaghan. Corpl R.S.M.

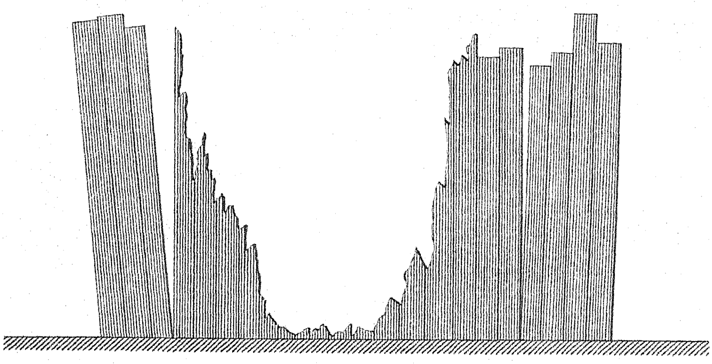
EXPERIMENT N.º 4.

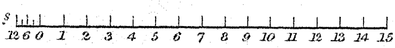
With a Charge of 60 lbs of Gunpowder.

Stockade before the Explosion.



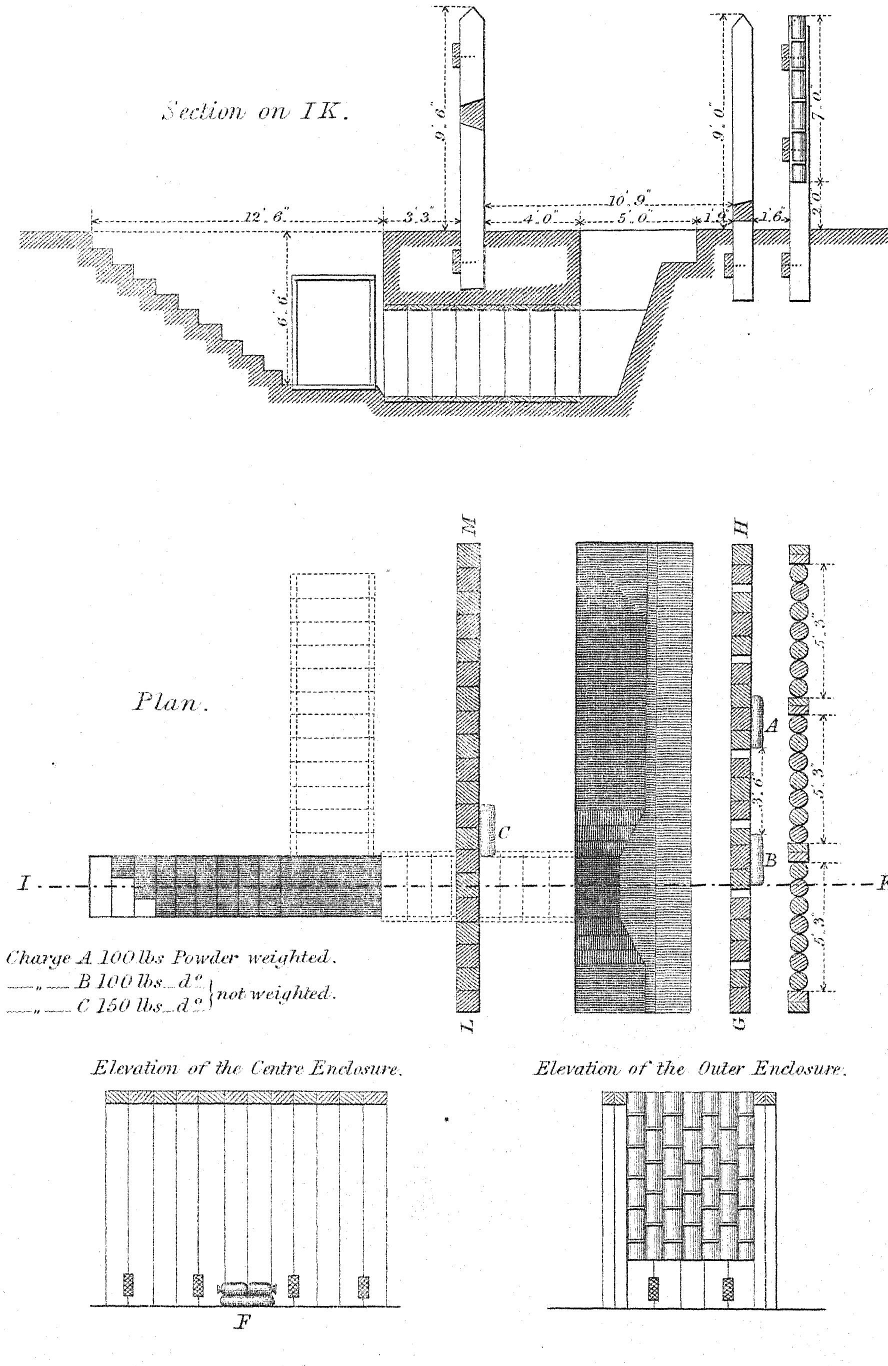
Stockade after the Explosion.





Drawn by A. Callaghan. Corp.l R.S.M.

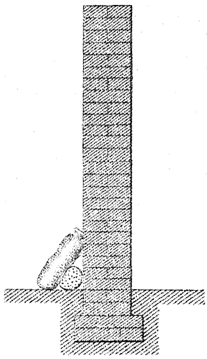
DRAWINGS OF A STOCKADED WORK similar to that Constructed by the New Zealand Chief "HEKI".



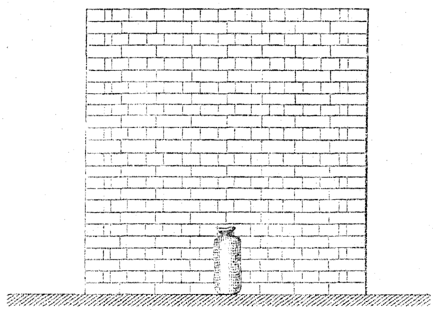
DEMOLITION OF BRICK WALLS.

Charge 6 lbs of Powder weighted.

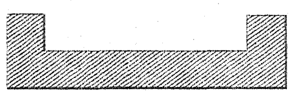
Section of Wall before the Explosion.

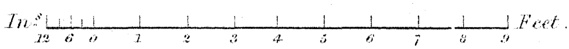


Elevation of Wall before the Explosion.

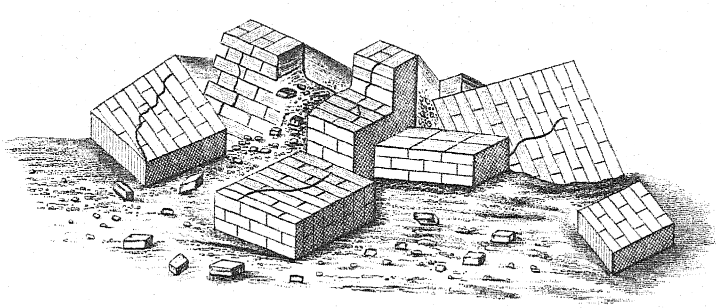


Plan of Wall.





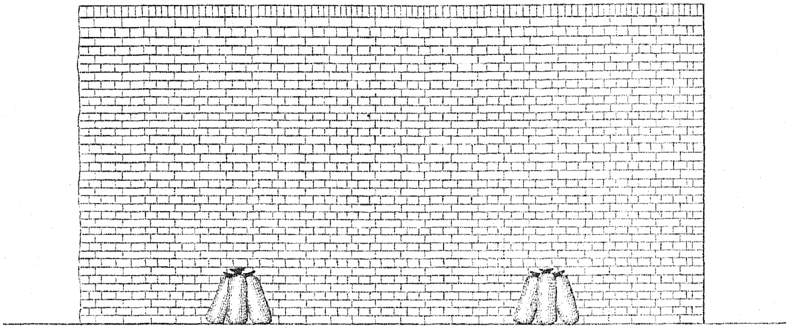
Appearance of the Wall after the Explosion.



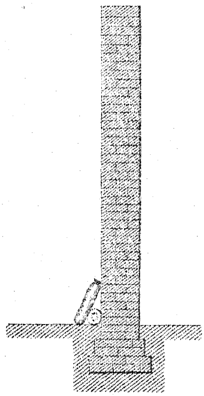
Drawn by A. Callaghan. Corpˡ R.S.M.

DEMOLITION OF BRICK WALLS.
With two Charges each of 60 lbs of Gunpowder.

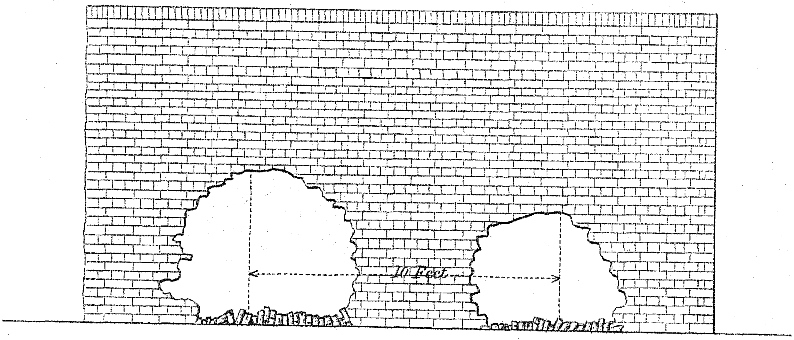
Elevation of Fire Barn Wall.

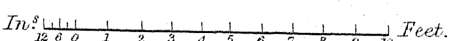


Section of Fire Barn Wall.



Elevation of Wall after the Explosion.





Drawn by A. Callaghan, Corpl. R.S.M.

W.A. Beever, Sc.

of the wall. The brickwork was generally so very much damaged that it was pushed over with ease by four men.

Experiment No. 5. *Wall No.* 3, similar in every respect to Walls Nos. 1 and 2.

A charge of 10 ℔s. of powder in one bag was applied to the foot of the face of the wall, and a bushel bag filled with earth was placed in front of and resting on the charge of powder.

The explosion produced complete demolition of the wall and piers.

Experiment No. 6. *Wall No.* 4, of 14-inch work, 6 feet high and 6 feet long, without counterforts or piers.

The charge was of 10 ℔s. of gunpowder, not weighted with bags of earth or sand.

The explosion produced no apparent effect upon the wall.

Experiment No. 7. *The same Wall.*—The charge the same as before (10 ℔s. of powder), and placed in the same manner, but weighted with one filled bushel bag laid upon the charge.

The wall was cracked by the explosion, but was not very materially injured.

Experiment No. 8. *Wall No.* 5, of 14-inch work, 6 feet long and 6 feet high, with piers at the extremities, 14 inches square. The depth of the foundation was 12 inches.

The charge of 8 ℔s. of powder, weighted with two bags filled with earth, was placed at the foot of the wall, near the centre.

The explosion forced some of the bricks out of the bottom of the wall, which was cracked in such a manner as to be quite unfit for further experiments.

Experiment No. 9. *Wall No.* 6, of precisely the same form and dimensions as Wall No. 5.

A charge of 20 ℔s. of powder, not weighted, was placed as in the previous experiment.

By the explosion the wall was very much shaken, so that it might have been easily pushed over by three or four persons pressing against it.

Experiment No. 10. *Wall No.* 7, precisely the same as Walls Nos. 5 and 6.

The charge was 15 ℔s. of powder, weighted with three bushel bags filled with earth, each standing on end, one being placed at either extremity of the charge, and the third in front of it. The charge was lodged, as in the two former experiments, upon the ground near the middle of the foot of the wall.

By the explosion the wall was totally destroyed.

Experiment No. 11. Plate VII. The enclosure wall of the fire-barns on the left of Chatham Lines is of good brickwork, 14 inches thick, with piers at intervals of 10 feet, and it is 10 feet high.

It was intended to breach this wall by two charges of powder, each of 60 ℔s., to be placed 6 feet only apart; but by an error they were placed 10 feet apart, and the consequence was that two openings were blown through the wall, as shewn in the sketch, instead of one large breach being formed; both holes were large enough, however, to let men pass through.

It may be deduced from these experiments, that a 14-inch wall, however well built, may be breached by charges of 60 ℔s. of powder, weighted with two or three bags of earth, the charges being not more than 5 or 6 feet apart.

Note.—Some interesting experiments were made at Chatham in September, 1850, under the direction of Colonel Sir F. Smith. A charge of 21 ℔s. of powder was placed in a bag, three sides of which were of leather, the other of light canvas: the latter being placed against a stockade which was 6 inches thick, the charge was fired from the centre by means of a piece of Bickford's fuze, covered with gutta percha, and wrapped in a piece of tinfoil, being inserted into it. Another charge of 21 ℔s. of powder was placed in a common canvas bag, and fired in the ordinary way against a similar stockade.

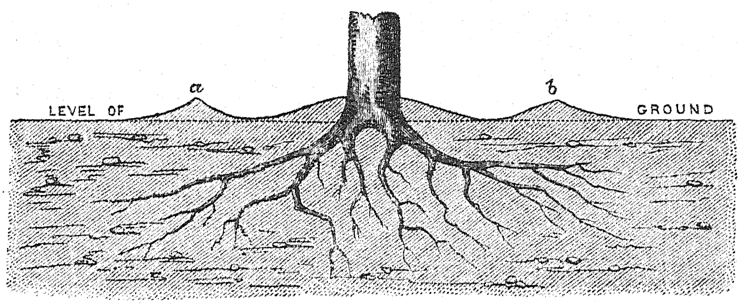
The former broke the stockade immediately above the bag.

The latter charge had no effect whatever.

The proposition appears to have originated with the Master Gunner of Pendennis Castle, Mr. Copeland.—*Editors*.

PLANTING TREES. — It may be observed that luxuriant trees, whether old or young, have the upper parts of the roots, where they divide from the stem, above the surface of the ground; and that, on the contrary, those which have a portion of their bark below the ground, generally exhibit an imperfect growth.

While a tree will live though its inside be hollow, it will die if a knife be passed round its trunk, so as to girdle the bark; the vital part not being in its centre, but just under the bark, where nature adds, season after season, to its growth. Hence, if the stem be so situated as that the bark be rotted, the same effect will be produced as if girdled by a knife.



The section suggests the manner in which a tree should be planted; and when on hard ground, it is desirable to surround it by a little bank, as shown at *a b*, to catch the rain in such a way as that it may soak to the fibres of the roots, leaving the stem dry.

Another cause of failure in transplanting trees is owing to the roots being too much cut away, instead of digging them up with care, and then placing them in the ground in a similar manner, copying nature as nearly as possible.—S. B. H.

POINT-BLANK. — In the *British Service*, "a piece of ordnance is said to be point-blank for an object when the axis of the gun and the object are in the same plane; which may be either parallel or inclined to the horizon: hence the point-blank range of a piece of ordnance, or its range at no elevation, is the distance from the muzzle of the gun to the first graze, measured upon a plane passing under the wheels, and parallel to the axis of the bore."

In the French Service—" But en blanc naturel, ou simple ~~single~~ment but en blanc, le ~~la~~ plus éloigné des deux points de recontre de la trajectoire avec la ligne de mire naturelle. Portée de but en blanc, distance du but en blanc à la bouche de la pièce." *

" Dans les canons, le but en blanc est comme dans les armes portatives, la seconde intersection de la trajectoire et de la ligne de mire naturelle.

" La portée de but en blanc dépend de la grandeur de l'angle de mire naturel; elle

* Aide-Mémoire à l'Usage des Officiers d'Artillerie.

varie pour les différents calibres et augmenté ou diminuée avec la charge qu'on emploie."*

Colonel Dundas† observes—"The but en blanc, in French nomenclature, is the range of the projectile from a gun, laid with the line of metal elevation, or angle de mire, 800 yards being given as the range with that elevation, and one-third the weight of shot in powder as the charge: it is presumed that the dispart (Anglicè) of the gun is about 1°, which makes the power of the 30-pr. French and the 32-pr. English nearly equal. In the French Service the tangent scale or the hausse is divided for distances, and not for any definite angle.

"The point-blank range of a gun, in the English Service, is the distance from the muzzle of the gun at which the projectile strikes the ground, after descending, by the force of gravitation, the height it is placed above that plane on which it is fired.

"It is evident that there is much vagueness in the term 'point-blank range,' for guns are seldom on the same height of carriage, and therefore their range is unequal; moreover, it very seldom happens that the ground over which the projectile passes is a dead level: if fired over an ascending plane, the resistance of the projectile in passing out of the gun is increased, and over a descending plane diminished; consequently the ranges are increased and diminished."

It would seem that *point-blank*, in the French Service, is purely an arrangement of the sight, whilst in ours it is considered to shew the absolute power of the gun; but there are so many contingences connected with this power, such as windage, length of the piece, and thickness of metal, that any just comparison in pieces of ordnance is very difficult.

Practically, for all useful purposes, *point-blank* may be deemed as the line of no elevation or depression of a piece, whether *cannon*, *carbine*, *rifle*, or *musket;* and the *point-blank range* the distance which they will carry a ball without elevation or depression, varying according to its construction. This explanation applies equally whether the object fired at is either horizontal or upon an ascending or descending plane.

Every gunner, rifleman, or musketeer should ascertain the point-blank distance of his piece, or, in other words, at what range he can fire and hit the object or bull's-eye of a target, by a direct aim, without elevation or depression: the necessary elevation and the depression, not of much consequence, may be found by practice, or by reference to Tables of Artillery and Musket-ball Firing, given in this work.—G. G. L.

PONTOON. — The pontoon or metal open boat or punt with flat bottom, in the British Service, may be considered as obsolete: the word is retained in other forms, as Blanchard's Pontoons, India-rubber Pontoons, and Major-General Pasley's Pontoons.

The pontoon was of metal over a frame-work of light scantling, tinned inside and out (see figure in the next page): the pattern is very old, and they were used in all the wars in Flanders, and drawings of one may be seen in Müller's work on Artillery.

Although imperfect, heavy, and difficult of transport, the pontoon was the only resource for a Bridge Equipment with the armies under the Duke of Wellington, in his Peninsular and French campaigns, for the passage of rivers. These pontoon equipments formed a part of the Engineer Establishment in those countries, with a detachment of Royal Sappers and Miners, and a few seamen.

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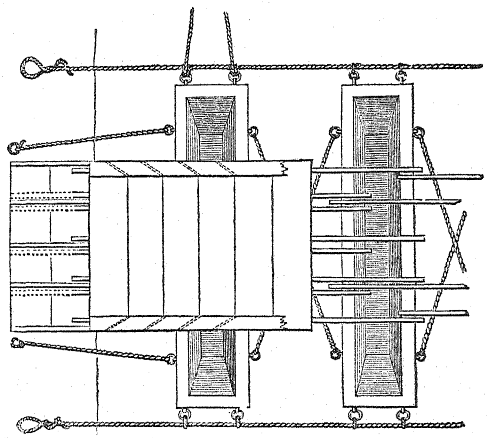
* Piobert. † Inspector of the Royal Foundry, Woolwich.



Part of a Pontoon Bridge.—Scale 14 ft. to an inch.

Dimensions and Weight of Tin Pontoons. *

		Large Pontoon.			Small Pontoon.		
		ft.		in.	ft.		in.
Outside measure.	Length at top . .	21		1	16		10
	,, ,, bottom .	16		8	13		4
	Breadth	4		10	4		0
	Depth	2		$3\frac{1}{2}$	2		0
		cwt.	qrs.	lbs.	cwt.	qrs.	lbs.
	Weight of pontoon . .	9	1	24	6	3	16
	,, ,, appurtenances	12	3	$9\frac{1}{2}$	8	2	2
	,, ,, carriage . .	12	3	7	11	3	21
	Total weight . . .	35	0	$12\frac{1}{2}$	27	1	11

Each pontoon had a carriage for transporting it, and the following appurtenances:

6 chesses for flooring	1 grapnel	1 sheer-line
6 baulks, or beams	1 pole	1 boat-hook
1 gang-board	4 spring-lines	1 maul
2 oars	1 cable	4 pickets, &c.
1 anchor		

A Pontoon Train was composed of 36 pontoons, one-half of which usually formed a Bridge Equipment with our army in the Peninsular War.

Equipment.	Carriages.	Horses for each.	Total of Horses.
Pontoon carriages	36	6	216
Spare ditto	4	6	24
Forge waggons	2	6	12
Boats mounted on carriages .	4	6	24
Waggons for tools	2	4	8
Carriages for stores . . .	8	4	32
	56	..	316

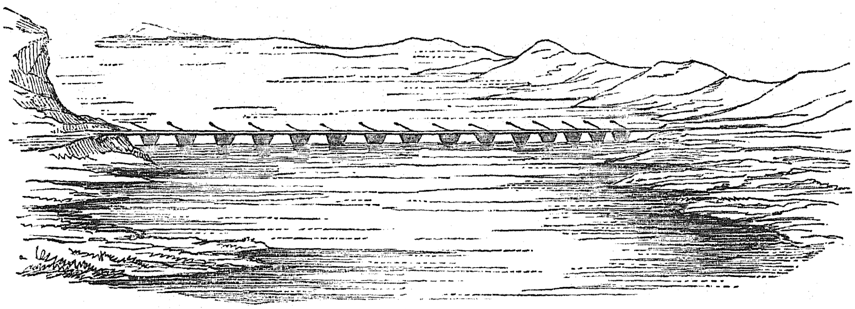
* From General Sir Howard Douglas's work on Bridges.

With a well-arranged train of pontoons, and expert pontooners, the time to construct a bridge was at the rate of $1\frac{1}{2}$ minute for each pontoon.

Independent of their unwieldy nature, and the difficulty of transporting the old metal pontoons, as described above, they were only suited to tranquil streams, not subject to sudden floods; for if any sudden rise of the water occurred, or if the river became disturbed by wind, they filled and went down.

A perfect Pontoon Bridge Equipment, combining facility of transport with the quick means of passing armies over considerable rivers, does not seem to have been yet organized.

See also articles 'Bridges,' and 'Passage of Rivers.'—G. G. L.



Pontoon Bridge—formed across the river Eslar, in Spain, in 1813.

POSITION, MILITARY. — A *Military Position* is simply the extent of ground which an army occupies either for the purpose of engaging with an enemy, or of advancing to a combat.

The advantages which military positions should possess must have relation to some particular object; and if nature does not supply them, they should be supplied by art.

The object of a military position must be deemed defensive; and the natural consequence of the occupation of ground, whether permanently or for the moment, is to receive an enemy on the spot selected for the position.

The qualities necessary are—1. That the space occupied should be in proportion to the number of troops.—2. That the flanks should be covered by obstacles either natural or artificial, so that an enemy cannot act upon the wings or rear of the order of battle.—3. The field of battle must be open, and permit the movements of the troops; and the roads and openings in rear sufficiently clear to allow them to retreat, in the event of the position being forced.—4. The military features of the position should be chosen with such judgment, that an enemy cannot penetrate the line without running the risk of being taken in flank, and being beaten by an inferior force.

These qualities should be considered with reference to whether the army in position is for offensive or defensive purposes: if for the former purpose, a ready access in front is indispensable, and the means of advance open for offensive operations;—in the latter case, the auxiliary defence by field-works should be used as explained under the article 'Field Fortification;' and if the position be temporary, or likely to be so, by the enemy taking another line of offensive operations, when he ~~or~~ has the means of so doing, the first part of that article will afford the information required how to fortify the position suitably to the occasion.

If the position is occupied for the purpose of covering a country effectually, so that

it should be secure during the War, or a frontier or line of country, or the capital of a territory, the defensive measures should be adopted as recommended in the second part of the article 'Field Fortification,' and in the Appendix to it.

There are three good examples applicable to permanent positions worthy of attention :

1. The defence of Provence in the early part of the 18th century, by Marshal Berwick.
2. The defence of Ardennes by the Republican army in 1792, by General Dumourier.
3. The defence of Lisbon by the Duke of Wellington in 1810, called the 'Lisbon Lines.'

One of the most difficult questions is to define the number of troops necessary to defend a given spot. The position in front of Lisbon, extending upwards of twenty miles, was not occupied by a larger force than that at Waterloo, which did not cover three miles ; in fact, it is a practical one in reference to the nature of the ground, and purely tactical.—G. G. L.

POSITION, RETRENCHED.*

"Ceux qui proscrivent les lignes et tous les secours que l'art de l'ingénieur peut donner se privent gratuitement d'une force et d'un moyen auxiliaires jamais nuisibles, presque toujours utiles et souvent indispensables."

"Until recent experience, it was fast becoming an axiom, that an army receiving battle in position must be beaten, and that no skill in occupying and strengthening, nor firmness in disputing and maintaining ground, could balance the advantage of free and concentrated movement, and the moral confidence arising from being the assailant. * * * *

"It is, however, unnecessary to revert to past history to shew the value of field-works, as in the recent battle of Borodino, a few simple redans, hastily thrown up to cover the left flank of the Russian position, paralyzed for hours two French corps d'armée, and had nearly proved equally fatal to the fortunes of Napoleon as the redoubts at Pultawa to those of his prototype Charles. Indeed, the attack of Dresden, which failed in consequence of the assailants being opposed by a slight field retrenchment, and many other events of the recent campaigns, leave no doubt that field-works judiciously disposed may still be rendered valuable auxiliaries, even to the most numerous and most active armies.

"To effect this, and apportion works justly to cover a country, or strengthen a proposed field of battle, is the most difficult application of the Engineer's art, being subject to no fixed rule, but merely founded on general principles, requiring to be modified on each occasion from an innumerable variety of circumstances, both physical and moral.

"A just idea of these principles can only be acquired through a knowledge of tactics, and of the powers of troops under different orders of formation and movement; which, well understood, can scarcely fail to produce a feeling that works ought in every situation to be accessories and aids to the manœuvres of troops, and never principals of any defensive field system.

"Posting troops to fight a general action, or strengthening the front of an army when so posted, are details founded on the foregoing principles, which for the same

* From 'Memoranda relative to the Lines of Torres Vedras;' in 'Journals of Sieges,' by the late Major-General Sir John T. Jones, R. E., vol. iii. 3rd edit. 1846.

reasons scarcely admit of theoretic elucidation, and the knowledge of them can only be fully attained by long service with an active corps.

"Considerable insight into such details may, however, be gained by studying the principles on which various fields of defensive combat have been occupied by skilful Commanders.

"In these it will be seen that a rocky height, a knoll, a wood, a village, and even a single house, have frequently formed the prominent flank or defensive posts; and instances might be adduced where each of the above obstacles have mainly contributed to the repulse of the assailants; and on the contrary, where such posts, injudiciously occupied or ill-supported, have led to discomfiture or the loss of entire divisions of the defensive force. * * * *

"There is, however, a very serious obstacle to the employment of the art of retrenching positions, which is, that after an army has taken up its ground, and a battle becomes inevitable, there is seldom time to throw up works of sufficient strength to be depended upon; and it is scarcely possible, in any moderately open country, to select a position to be fortified in advance for the protection of a frontier or a capital which an Enemy will not find roads to turn and render useless. Thus, in allusion to the battle of Waterloo, had the ground been strongly retrenched during the spring, Napoleon would naturally have avoided it by marching on Brussels by the road of Hal, and therefore such preparatory labours seem only advisable in peninsular situations, or to block up the entry, or dispute the sortie of a mountain-pass, occupy the interval between two fortresses, or for some other specific and very limited object.

"Even in such favourable situations, attention should be directed rather to the improvement of natural obstacles than to the erection of artificial lines of defence;* and where works cannot be dispensed with, they should, as far as practicable, be enclosed, independent, and capable of defending themselves. Nothing can be more vicious than to cover an extensive tract of country with a regular system of bastions and redans, as recommended in most Treatises on Field Fortification. Such long systematic lines of defensive works, besides the great expense, labour, and publicity attending their formation, have the serious defect of being of no strength, unless equally guarded throughout; and further, when attacked, the defenders have, in consequence of their flanked trace, to man an alignment of nearly double the length of the front to be defended, and are utterly incapacitated from making any instantaneous or powerful forward movement: they therefore necessitate the worst possible disposition of troops for offence or defence, and must be regarded as inadmissible under the present system of tactics. Indeed, such long defensive lines, even when most in repute, at the end of the seventeenth and commencement of the eighteenth century, were invariably forced as often as attacked, and it is difficult to conceive on what foundation their popularity so long sustained itself.

"Field defences, however, are not to be indiscriminately condemned or rejected because they are continuous or systematic. In order to strengthen the front of an army with judgment, it is necessary to consider every feature and every portion of the ground separately, and arrange such mode of occupation as shall best combine its particular defence with the general defence of the position. Thus, in parts unfavourable for manœuvring, it may be advisable to form a continued line of considerable extent, covered with every nature of obstacle, and having none but the most confined outlets, on the principle that a range of difficult heights would be scarped, or low ground inundated, to lessen the number of men on those points, and leave a super-

* See article 'Field Fortification.'

abundance of force for other points favourable for offensive movements. Again, since the employment of artillery in masses has been introduced, and that an irresistible fire, sometimes of hours' duration, now invariably precedes the advance of the columns of attack, it will frequently prove a good measure, in situations where natural cover cannot be formed from a cannonade, to create it artificially between all the prominent defensive posts.* Thus, each furlong of ground being duly considered, and the nature of defence best adapted to the locality being formed, the whole front of an army may occasionally be covered with lines of works, which, while they augment its defensive powers, leave its movements perfectly free.

"Continuous lines, of the short extent of a mile or two, may frequently be resorted to with advantage, in situations where the flanks can be naturally or artificially secured, as on a river or a fortress.

"Such lines, in communication with a fortified town, when composed of fronts of fortification or other flanked trace, and made of a profile not to be assaulted, are well suited to facilitate the defensive manœuvres of an inferior army, and also to augment the defensive powers of the fortress itself, by occupying important tracts of ground which could not be included within the permanent works. In such cases they are usually denominated Retrenched Camps,† under which character they form a medium of defence between field-works and permanent fortifications, which can be resorted to on any pressing emergency arising from defeat, and may be generally recommended by an Officer without hesitation; for if it be not convenient to man them fully, their evacuation, after a show of resistance, neither compromises the retreat of the defenders, nor detracts from the original strength of the fortress.

"Experience affords many proofs of positions of two or three miles length of front, which could not be turned when retrenched on a field profile, being capable of an excellent defence. * * * * *

"It is apparent, however, that isolated and unsupported field positions of this nature, retrenched on a field profile, besides being liable to be turned, and the defenders shut up as in a trap, and made prisoners, partake of all the defects of longer continued lines in proportion to their extent, and are in the same proportion objectionable. * * * *

"None of these objections to continuous lines, however, apply to retrenchments formed of enclosed and isolated works, each capable of a good resistance, as the intervals between them do not require a line of supporting troops; and after furnishing garrisons for the works, the army may remain in masses, sheltered from cannonade by some irregularity of the ground near the summit of the heights; or if such be not found, on their reverse, immediately below the crest, ready to move in compact and formidable bodies on any menaced point, or form into line or manœuvre on the posts taken up, so as best to parry the efforts of the assailants.

"It seems to be an indispensable condition of such field-works in aid of an army, whether prepared at leisure or during active operations, that they be of a profile and capability of defence to resist an assault,—that they be securely closed in the rear, placed sufficiently near to and so disposed as to flank each other, and armed with sufficient artillery to prevent heavy columns passing between them without being thrown into disorder from severe loss; or else made of a size to contain a force likely to prove formidable to the rear of a column which should venture to pass them. In

* "This might be effected by means of a sunken trench, like a parallel at a siege, made to connect a whole chain of redoubts. Such an expedient would cover infantry from the fire of guns without impeding their forward movement in line, and openings might be left for the advance of the cavalry and artillery, or they might act in masses on the flanks."—*Author.*

† See 'Camp, Intrenched,' vol. i. and Plan.

this case, indeed in all cases, the outlets from, and intervals between works, should give every freedom for the movement of troops compatible with security from assault or being passed.

"On this point it may be as well to observe, that detached enclosed works, in front of an inferior army acting on the defensive, ought to be regarded as vital points, performing certain functions of themselves, and their garrisons be considered as integral parts of the works, destined to share their fate—to triumph or fall with their post, and not as portions of the army to be protected and withdrawn. Under this view, the defensive corps being left unshackled in their movements, and their part being confined to the discomfiture of the Enemy, they will be prepared to seize the favourable moment, and advance to the attack when the redoubts shall be most warmly engaged, or their fire have thrown the assailants into confusion; so that to derive full benefit from works, as much judgment is required in posting and manœuvring the force to be strengthened, as in placing the works themselves.

"This leads to a consideration of the just proportion between the garrisons of detached works and the army they cover, and also of the length of front along which works may be allowed to extend for given numbers of men. On the first point it may be observed, that the better the troops composing the defensive army, the fewer should be the works, for it can seldom be advisable to confine any considerable body of a manœuvring and steady force in an enclosed work, unless it be the key or main support of a position; but when an army is composed in great part of ill-disciplined and unsteady troops, artificial defences can scarcely be too numerous.

"The extent of front which works may cover need in strictness only be limited by the power the army possesses of succouring, in sufficient time, any and every work that may be pressed, so that a ready or difficult communication will frequently decide the eligibility of occupying a distant point; but as strength is invariably gained by concentration, no ground should be occupied that is not intimately connected with the main object of defence, even if invitingly convenient. On this head no better rule can be followed than to inquire, previously to occupying any point, whether it be essential to the support or safety of the main body of the army; and on each occasion an Officer must exercise his judgment to modify and turn local circumstances to advantage on the unchangeable basis of science. It cannot, however, be too strongly borne in mind by those planning defensive expedients, that troops are the principals, works the accessories of defence,—that the latter must invariably be dependent on and limited by the former, and consequently that every point superfluously retrenched is an unnecessary source of distraction and division of force. Field-works can never without hazard be left to their own garrisons; and reverting to the Lines of Torres Vedras, which would seem to warrant the creation of an unlimited number of defences, it may be confidently predicted that any Commander not possessing the utmost promptitude, decision, and skill in manœuvring troops, who, trusting to that example, shall attempt to defend against a superior, or even equal force, a tract of four-and-twenty miles of country as a fortified position, will infallibly be beaten; and that an Engineer who should, on any ordinary occasion, copy the extended system of isolated redoubts and retrenchments practised in front of Lisbon, would, instead of adding to the strength, altogether cripple an army.

"But whenever, by the foresight and skill of the General and the exertion of the Engineer, the arrangements of the troops and works shall be in happy unison, and a defensive army well posted shall have its front covered with works constructed on just principles, its force will be incalculably augmented, and its defeat rendered almost impracticable. Even a few works, thus judiciously disposed on the principal features of the ground, or to sweep the approaches, could not fail to add materially

to the powers of movement and resistance of a defensive force; as will frequently the most trifling efforts of labour, such as loopholing buildings, barricading streets, blocking up or opening communications, destroying bridges or roads, or the fords of a river, felling abattis, forming emplacements for field-guns, or the slightest cover from cannonade; and an active and zealous Engineer will generally find opportunity on the eve of a battle to strengthen, by some of these various labours, the fronts and flanks of a defensive force.

"In making this statement, it is not forgotten that since the improved organization of armies has given them an increased facility of movement, and a consequent celerity and boldness of enterprise, placing legs almost on an equality with arms in war, time is rarely allowed to a defensive force for perfecting defensive expedients; but this consideration, so far from being deemed to excuse the attempt, should only stimulate an Engineer to increased exertion. * * * * The most simple exercise of his art will occasionally prove their paramount utility; and as it not unfrequently occurs, even after hostile armies come into view, that days pass in reconnoitring or preparation for attack, who can say on such occasions to what extent activity and intelligence may not gain artificial strength for a field of defensive action, and consequent character and reputation for an Officer?" *

PRISONS, MILITARY: DISCIPLINE AND MANAGEMENT.†—The question of Military Imprisonment having engaged much public attention during previous years, was very fully inquired into by Commissioners appointed for the purpose in 1835 and 1836: little, however, was done at the time to give effect to their recommendations; but Sir Henry (now Lord) Hardinge, on assuming office as Secretary at War in 1842, proposed to his Grace the Commander-in-Chief that a Committee should be appointed to investigate the subject, and report their opinion on the means of carrying into effect a regular system of Military Imprisonment as a substitute for the general infliction of corporal punishment.

A Committee, of which Lieut.-General Earl Cathcart was President,‡ was appointed accordingly, and received their instructions from Sir James Graham, Secretary of State for the Home Department. The chief points to which the attention of the Committee was directed were the following:

Whether it might not be desirable to mature for the future a permanent scheme as regards the establishment of prisons, in which military offenders alone shall be confined, and in which they might be subjected to the discipline and punishment best suited to their military habits, and to the nature of their offences.

Whether any and what changes were required to be made in the Mutiny Act, with reference to this subject.

Whether, without any change in the law, a system of military punishment might not be laid down which would adapt itself to the greater portion of the cases of soldiers sentenced to confinement for military offences. Whether drill, breaking stones, or other hard labour, might not be substituted for confinement in civil gaols.

The Committee were to report upon the nature of the confinement, the system of

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* See article 'Fortification, Field,' vol. i.

† By Colonel Jebb, Royal Engineers, Inspector-General of Military Prisons.

‡ The following were the members of Lord Cathcart's Committee: Colonel Grant, commanding Grenadier Guards; Colonel Godwin, late commanding 41st Regiment; Major Jebb, R.E., Surveyor-General of Prisons; Rev. D. Nihill, late Chaplain of Millbank Penitentiary.

drill, the hard labour, the diet, the clothing, the bedding of the prisoners. They were also to take into their consideration the powers to be given to the Officers in charge to repress refractory and insubordinate conduct amongst the prisoners, whilst undergoing their sentences; and who in their judgment should be invested with the superior powers of Visiting Justices, and exercise superintendence and control.

The Committee commenced their sittings early in the spring of 1844, and continued them till the end of June of the same year. Their views on the means of effecting the proposed objects were as follow:

With reference to the provisions to be made in the Mutiny Act for establishing military imprisonment, clauses were proposed for empowering the Secretary at War to establish military prisons, and appoint visitors and officers, &c., and to confer upon him generally the same powers that are vested in any of Her Majesty's principal Secretaries of State, with respect to civil prisons. Another clause was proposed for the purpose of giving to the superior Officer in command, whose duty it might be to confirm the sentence of a court-martial, the power, which he did not previously possess, of selecting the place, whether a civil gaol or a military prison, in which the offender should be confined, and from which he might at any time remove the prisoner, in order that the prisoner might undergo the remainder or any part of his sentence in some other public prison or place of confinement: henceforward, therefore, courts-martials do not, in their sentences, notice the place of imprisonment.

With reference to the question of establishing prisons in which military offenders alone might be confined, and in which they might be subjected to the discipline and punishment best suited to their military habits and the nature of their offences, the Committee took into consideration the minute of Sir Henry Hardinge, dated the 24th of May, 1842, the Report of 1837 of the Home Inspectors, and the opinions of various military authorities referred to in these and other documents; and they thus expressed their opinion:—"That assuming, *in limine*, the concession to public opinion of the general disuse, though not total abolition, of corporal punishment, and feeling the insuperable difficulty of devising any new satisfactory penalty, repressive of crime in the Army, the Committee considered they had no alternative but a choice between civil and military prisons, and they could not hesitate to prefer the latter, and to come to a decisive conclusion in favour of a permanent scheme as regards the establishment of prisons exclusively for military offenders."

They go on to say, that in considering the subject generally, there were two species of punishment to be provided for, viz. solitary confinement, and imprisonment with hard labour.

In reference to the former, they did not propose any change in the principle of the existing law, but merely suggested an amendment which was incorporated into the Mutiny Act, for enabling courts-martial to sentence prisoners to solitary confinement, (not only, as formerly, to periods not exceeding one month at a time, or three months at different times with intervals of not less than one month,) but also for *shorter periods*, with intervals of imprisonment with hard labour of not less duration than the periods of solitary confinement.

Classification of Prisoners.—With respect to sentences of imprisonment with hard labour, or mixed sentences involving periods of hard labour alternating with solitary confinement, the Committee recommended associated labour under a rule of silence in preference to what is technically called 'the Separate System,' but upon this they grafted a principle of classification to which they attached considerable importance.

To any one conversant with the operation of this principle in ordinary prisons, and

with a knowledge of its having been repudiated by the best authorities on prison discipline, it will at first sight appear extraordinary that the attempt should be made to revive it in military prisons. It is necessary, therefore, to explain that *classification* under the Gaol Acts is based upon the *crime* for which a prisoner happens to be sentenced, by which any one frequently re-committed for different offences may find himself alternately associated with felons or misdemeanants, or others, as the case may be: this affords no moral standard by which to make a classification, and therefore leads to much practical evil.

The classification recommended by the Committee, on the contrary, is based upon *character*, and will be best understood by the following rule:

"The Governor will bear in mind that the object of classification is, first, to protect the young soldier, and the less hardened offender, from the mischievous consequences of association with worse characters; and secondly, to hold out an inducement to all the prisoners to behave well in prison, by the hope of reward and the fear of punishment, in being either promoted to a higher class or degraded to a lower one. In applying this principle, the worst characters, such as have been convicted of 'disgraceful conduct,' or who may appear to be confirmed drunkards, or incorrigible and hardened offenders, and prisoners who have ever been subject to corporal punishment, would obviously be placed, on reception, in the third class.

"Those prisoners who do not come under this description, and of whom better hopes may be formed, will, as an invariable rule, be placed, on reception, in the *second class;* but the Governor will exercise his discretion in making an early selection for promotion to the *first class* of any prisoner, who, from the nature of his offence, and previous good character, appears deserving of such distinction, or who, from his youth or other circumstances, requires to be protected from the bad effects of associating with worse characters.

"The *first class* shall be composed of those prisoners who, from their quiet, orderly habits and general good conduct under punishment, may appear deserving of being promoted from the *second class*, after some experience has been gained of their characters.

"In like manner, prisoners in the third class will, by good conduct, be eligible for promotion to the second class.

"Prisoners in either the first or second classes will also be liable to be removed to a lower class for misconduct.

"The classes will be distinguished by badges marked as first, second, or third class, attached to some conspicuous part of their prison-dress."

The difference in treatment between the first and second classes is, that the former are generally exempted from shot drill, and, during the hours prescribed for that exercise, are employed under a warder of the Royal Artillery in working heavy guns, or in labour not of a penal character. They have also a meat dinner on Sundays, and the silence enforced on other classes during the evening is relaxed, and they are permitted to converse in an orderly manner.

The distinction between the second and third classes consists in the former being exercised with 24lbs. shot, while the latter carry 32lbs. shot. The second class also receive school instruction from 6 to 8 o'clock in the evening, whilst the third class are employed in picking oakum.

These distinctions between the classes may appear trifling, but experience has shewn, by the endeavour that is generally made to obtain the advantage of promotion to the higher class, that they possess the required influence.

Hard Labour.—With respect to hard labour, the Committee were of opinion that it

was an object to avoid any description of labour or exposure which had a tendency to *degrade* the soldier. With this view they objected to the use of the tread-wheel, and to the employment of prisoners in gangs outside the prison; and in lieu of these ordinary methods of enforcing sentences of hard labour, they proposed piling and unpiling heavy shot, knapsack drill, working heavy guns, or other such employment.

Diet.—With respect to diet, it was recommended that it should be such as would maintain the prisoner in perfect health, so that, on rejoining his corps, he should be fit for immediate duty. They, however, strongly urged their opinion that no comfort, not essential to health, should be allowed, and that a prisoner should be made to feel, during the whole period of his confinement, that his state and condition was, in all respects, much worse than when doing duty with his regiment.

Governor and Subordinate Officers.—On the subject of the officers to be appointed to the charge of the military prisons, the Committee were of opinion that, "considering the extent of the prisons, the power to be vested in the chief Officer, and his responsibilities, the Governor ought to be a Commissioned Officer; and that an Officer possessing the qualifications of a good Adjutant would be the most suitable for the situation."

They conceived it to be an object to retain the advantages of that chain of responsibility which exists in the Service, and therefore recommended that the chief warder, or second in command, should be of the grade and possess the qualifications of an effective serjeant-major; that the warders should be of the grade of colour-serjeants; and their assistants, of serjeants and corporals to be taken from the Pension List.

Visitors or Governing Bodies.—With respect to the general superintendence of the military prisons, the Committee suggested that visitors should be appointed by the Secretary at War, and a power to that effect was given by the Mutiny Act.

They were of opinion that the following Officers would be suitable as Visitors to military prisons:

The General, or the Officer commanding the district or station;
The Assistant Adjutant-General;
The Assistant Quarter-Master-General, or the Brigade-Major;
The Garrison Chaplain;
The Principal Medical Officer;
The Commanding or Field Officers of regiments or corps in the district or station for the time being;

and such other persons as the Secretary at War might appoint.

Duration of Imprisonment, and Expense.—With reference to the duration of imprisonment, the Committee observed, that under the law as it then existed, district and general courts-martial had an unlimited power with respect to the periods for which they might award imprisonment, (excepting in the case of solitary confinement,) and that the effect was sometimes to extend a man's imprisonment, and consequently his absence from duty, to one, or even two years. It is very generally admitted that the punishment of imprisonment, if too long protracted, loses much of its moral effect, from the prisoner's becoming callous to his situation, and no sufficient advantage is therefore gained to compensate for the evil of his being so long absent from his regiment. The Committee therefore recommended that the actual detention of a soldier in prison should not exceed six months, except by sentence of a general court-martial.

On the question of the expense of maintaining the military prisons, the Committee stated their opinion, that the saving accruing from the stoppage of the soldiers' pay

The following is a statement of the ages, services, country, and religion of the prisoners admitted in 1847, 1848, and 1849:

	1847.	1848.	1849.		1847.	1848.	1849.
AGES.				SERVICES.			
Under 20 years	1,126	966	575	2 years and under	1,656	1,567	986
From 20 to 30	2,277	2,598	2,446	Under 7 years	1,180	1,411	1,554
„ 30 to 40	410	421	482	7 to 14 . . .	784	850	798
Above 40	37	24	30	14 to 21 . . .	190	158	171
				Above 21 . .	40	23	24
Total	3,850	4,009	3,533	Total	3,850	4,009	3,533
COUNTRY.				RELIGION.			
English . .	2,089	2,038	1,873	Protestant . .	2,313	2,311	2,121
Scotch . .	371	449	405	Presbyterian .	330	358	325
Irish . . .	1,390	1,522	1,255	Roman Catholic	1,207	1,340	1,087
Total	3,850	4,009	3,533	Total	3,850	4,009	3,533
CRIMES.							
Desertion					1,481	1,431	970
Absence without Leave					823	822	977
Drunkenness					703	851	795
Disgraceful Conduct					187	200	153
Other Crimes					656	705	638
				Total	3,850	4,009	3,533

Expense of the Military Prisons.—The following is a statement of the expenses of the military prisons, from which it will be seen that the credit to the Government arising from the stoppages of the soldiers' pay during confinement more than repays the entire cost of the prisons, and that the saving under this head amounted in 1849 to £1437. The annual cost of each prisoner has been £18. 16*s.*

	1846.	1847.	1848.	1849.
	£.	£.	£.	£.
The total cost for pay and allowances of officers, and for the subsistence and washing of the prisoners, was	11,094	13,741	14,801	14,106
The full-pay and beer-money of prisoners in confinement, not issued, amounted to	10,563	13,310	16,171	15,543

Effects of the New System of Military Imprisonment.—In considering the effect of the present system of military imprisonment in repressing crime in the Army, it must not be forgotten that it is in a great measure to be regarded as a substitute for corporal punishment; and, in attempting to make any comparison between present and former times, the question becomes somewhat complicated; indeed, it is impossible, from circumstances, to institute any very close comparison. Some opinion may, however, be formed from the following fact.

With a view to enable the Committee to arrive at a conclusion as to the number of cells it would be necessary to provide in the military prisons and in the different garrisons and barracks, returns were furnished from different districts of the number of men undergoing imprisonment by sentence of courts-martial.

From these returns it appeared that in 1843 the average number of soldiers of the Line undergoing imprisonment at any one time by sentence of courts-martial was about 20 per 1000.

The nine military prisons established in England, Ireland, and Scotland have now been in operation three or four years, and the statistical records shew that the average number of prisoners in confinement at any one time during that period has been rather less than 10 per 1000, as compared with the force in the district sending prisoners to each prison.

This, however, does not afford the means of making an exact comparison, in consequence of a proportion of prisoners under sentence by courts-martial for short periods undergoing their punishment in garrison or barrack cells.

The returns furnished to the War Office shew that during the year 1848 there was a daily average number of about 1025 prisoners in confinement in cells, under the regulations issued by the Commander-in-Chief, of whom about one-fifth were by sentence of courts-martial.

In comparing this number with the strength of the Force using the cells, (which was 66,300,) it therefore appears there was an average of 3 per 1000 under sentence by courts-martial in the cells, which, added to the number in the military prisons, gives a general average of 13 per 1000 in confinement, instead of 20 per 1000, which was the average number in 1843.

Discipline.—The discipline now in force in the military prisons is in all respects in conformity with the recommendation of Earl Cathcart's Committee, and has, on the whole, worked in a satisfactory manner. In reviewing the subject, it will be seen that, by the prompt measures taken by the Secretary at War for giving effect to the Report of the Committee, the practice of committing soldiers to civil prisons soon became almost unnecessary. The gaols were thus relieved from a serious and inconvenient pressure; the soldier was not degraded by being placed by the side of a felon, and taunted by him as being on the same level; he was also spared the public exposure of being committed to a common house of correction, and at the same time was subjected to an effective punishment better adapted to his habits, and more likely to secure the objects for which he was sentenced.

Another great advantage was gained. The system of discipline in all military prisons is perfectly *uniform*, whereas, when prisoners were indiscriminately committed to civil prisons, there was the greatest uncertainty as to the degree and nature of the punishment which would be inflicted. But few prisons could be selected in the whole country where uniformity of discipline prevails. In some, the greatest strictness and severity is found, in others, the greatest mildness and laxity; in some, the strictest separation, in others, the most unrestricted and contaminating association; nothing, in fact, being so different as the degree of punishment inflicted in different prisons. The means of maintaining discipline, therefore, so far as it depended upon efficacious punishment for the repression of crime, was thus a matter of chance, influenced in a great measure by the character of the discipline in the nearest prison.

The primary object for which the regulations for the military prisons have been framed has been to repress crime in the Army, by creating a salutary dread of a prison; and subordinate to this object has been the prevention of the repetition of crime by the same individual in the endeavour to reform him.

It will be admitted by all that punishment and reformation are the main objects of penal discipline, and the question to be considered is the due adjustment of these elements.

In the routine of discipline which has been established, the prisoners are under strict superintendence and control, from 6 o'clock in the morning till 8 o'clock at

night, and have a fair share of hard labour to perform, consisting of shot exercise, drill, picking oakum, breaking stones, &c. In those prisons where separate cells are provided, each prisoner takes his meals alone and sleeps in his cell. In other prisons which were converted from existing buildings, the prisoners are associated at meals, and sleep in large rooms or bomb-proofs, but night and day they are under close supervision, and the strictest silence is maintained on all occasions.

If this routine be compared with the ordinary discipline of civil prisons, it will be found that although the hard labour is of a less degrading character, it is fully as severe.

As regards the reformation and welfare of a prisoner, the Governors are enjoined to bear in mind, that the chief object of establishing a prison exclusively for military offenders is to maintain discipline in the Army; and as punishment alone can hardly be expected to produce this effect, he should consider it his duty to endeavour to instil soldier-like and moral principles into the mind of every prisoner, letting him see that he takes an interest in his welfare, and, by his good advice and kindly admonition, endeavouring to convince him of his error, and to encourage him to aim at future good conduct, and the attainment of a respectable character in the Service.

The Chaplain also is directed to endeavour, by all the means in his power, and particularly by encouraging their confidence, to obtain an intimate knowledge of the character and disposition of all the prisoners: for which purpose he shall occasionally see and converse with every prisoner in private; and whenever he shall wish to instruct or examine a class of prisoners, he shall apply to the Governor. He shall establish an evening school, and frequently attend and examine the prisoners as to their progress, and give directions concerning their instruction; and he is expected to allot a considerable portion of his time to visiting, admonishing, and instructing the prisoners in their cells and rooms.

Among soldiers, as in all other bodies of men, there are to be found reckless and incorrigible characters, who can neither be subdued by punishment, nor encouraged to good conduct by kindness and forbearance; and it is very generally admitted, that repeated and lengthened terms of imprisonment fail in their effect with such men from their becoming habituated to the confinement, and thus ceasing to have any dread of it. During long periods of confinement there is also a great loss of service, a constant additional duty is thrown on the well-conducted soldier, and discredit is brought upon a regiment by the misconduct of, it may be, a very few men. Such characters are worse than useless in the Service, and it is the opinion of many Officers, that after repeated trials, they should be marked so as to prevent re-enlistment, and then be discharged.

The advantage of this course, in the cases of hardened and incorrigible characters, cannot be doubted; for whatever expense may have been incurred in training the soldier, no service is afterwards rendered to compensate for it. On the other hand, however, it must not be forgotten, that if the discharge of all such men were to become an established practice, and that great facilities for getting rid of them were afforded, it might operate with some as an inducement to commit crime with a view to obtain a discharge.

Several Officers have expressed their opinion that the discipline of military prisons is not sufficiently stringent and severe; that the comfort of the prisons, the facilities for cleanliness, the good diet, the bedding and warm clothing, and the advantages of being every night in bed, contrast favourably with the discomfort of many barracks and half-billet stations, and with the onerous duties, especially during inclement weather, that fall to the lot of soldiers serving with their regiments: others, who take a warm interest in the welfare of the *individual*, would advocate less hard labour and more instruction.

This question is of paramount importance. In considering it, however, it is necessary to keep in mind the different objects which are to be attained, in order that we may not lose sight of their relative proportions, and be carried away with the one idea of either punishment or reformation.

The repression of crime by corrective discipline depends mainly on the punishment operating widely *as an example*, and thus exercising a deterring influence on others, and in a minor degree by the individual himself being deterred from future offence from fear of the consequences, or by his being so reformed that he ceases to commit crime from a better motive than that of fear.

The first of these objects will be promoted by carrying into effect a system of discipline known to be of a severe and stringent character, such as will make men prudently resolve to keep clear of it if they can. It should also dwell on the memory of one who has once been subject to it, as a disagreeable and certain consequence of crime, and thus tend to prevent its repetition.

At the same time, however, that a severe discipline with more extended objects is maintained, there can be no doubt that efforts should be made to prevent the repetition of crime by an endeavour to reform the individual.

With the few hardened reckless characters that are to be found in every regiment, reformation is a very hopeless task; but with young soldiers under two years' service, and with many under sentence for 'desertion' and 'absence without leave,' (and these constitute the majority,) such a course cannot fail to have its effect.*

Among other things, it has been suggested that it would be of advantage to turn the labour of the prisoners to account, by placing it at the disposal of the Engineer Department, or using it for garrison purposes, in rolling and weeding parades, keeping the roads and drains in order, &c., instead of wasting it upon such unproductive labour as removing shot. This question, however, can only be considered in connection with the object of imprisonment. If crime could be repressed, and a prison be made an object of aversion and dread by giving prisoners the ordinary occupation to which they had been accustomed either before they enlisted or during their service, there would be everything in favour of applying their labour to some useful purpose; but it will be in the experience of all who are practically acquainted with the subject, that no ordinary occupation can be enforced to the extent of hard labour as contemplated by the sentence of the Court, or so as to be an effective punishment. It is not the value of the labour, but the question of whether it is adapted for promoting the main object of the sentence, which should be considered, and, as far as I am enabled to form an opinion, no labour will be found so productive in prisons, as that which is calculated to deter others, and the individual himself, from subjecting themselves to it. This main object cannot be accomplished by amusing prisoners by such employment as will only serve to lessen the tedium of their confinement.

On a careful consideration of the subject, I am not prepared to advocate a more lenient system of prison discipline for the repression of offences in the Army, because I consider it would fail in its object, and be, in the end, the least merciful course that could be pursued. All Officers of experience agree that the sentence on military offenders should be short, and if the punishment is to have a deterring influence on others, or on the individual himself, the discipline, during periods which do not in general exceed six months, must be of a severe character. During long periods, some

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* It will be found under the head 'General Statistics,' that in 1848, out of a total number of prisoners of about 4000, there were nearly 1600 under two years' service, and that of the same number of prisoners there were 2253 convicted of desertion and absence without leave.

relaxation in favour of instruction may perhaps safely be admitted, and at all times efforts to reform must be made; but I am satisfied of the necessity of preserving, under all circumstances, the general prestige of a severe punishment, either *by the length of the period of confinement*, or the *stringency of the discipline.*

Under a system calculated to inspire a certain degree of dread in the minds of soldiers, it may fairly be anticipated that many would be deterred from committing a crime, the detection and punishment of which was *certain;* and, during short periods, I should be inclined to place far more reliance on such a system in preventing the repetition of crime by the same individual, than on the effect of the better feelings and resolutions which might result from a system in which persuasion and compulsory education were the leading features. The one would operate widely on every man in the Service; the influence of the other, even under the most favourable circumstances, would be confined to the few individuals who may be subject to imprisonment, which, during an entire year, including recommittals, do not exceed 5 per cent.

It would surely be considered a great mistake to tamper with punishment, if it be designed to have any effect at all on crime, for the sake of the *possible* effects of leniency on so very small a proportion.

There appears, however, to be a tendency, at the present time, to take a very benevolent view both of crime and its consequences, and to hold exemplary punishments very cheap. Without entering into the various opinions that may prevail on such a subject, it seems reasonable to expect that, assuming simple imprisonment as the basis of discipline, it will be dreaded in proportion to the penal inflictions which may be given in addition, and cease to be so as they give place to the introduction of employment and instruction.

J. Jebb, *Lieut.-Colonel, Inspector-General of Military Prisons.*

EXPLANATION OF THE PLATES.

Plate I. represents the ground-plan of a military prison at Gosport, completed and occupied in 1850; and the construction may be considered to be based upon the several improvements deemed necessary after the experience of the previous seven years, as regards the health and discipline, the punishment of those convicted of offences, and their reform, subject to military imprisonment from one to six months, or in some cases from eighteen months to two years.

The main building, or prison, *a*, *b*, *c*, *d*, in Plate I., of which an elevation is given in Plate II., consists of three stories of cells. The cells are of nearly uniform size, $11' \times 7'$ (see also Plate III.), and connected by a long corridor: the latter is lighted from above and at each end.

The prison is warmed and ventilated by a furnace in the basement story and a shaft above, as explained in the longitudinal section in Plate II. Each cell has, besides, the means of receiving fresh air at the window.

Connected with the main building, and in rear of the centre, is placed the chapel, with a school-room below.

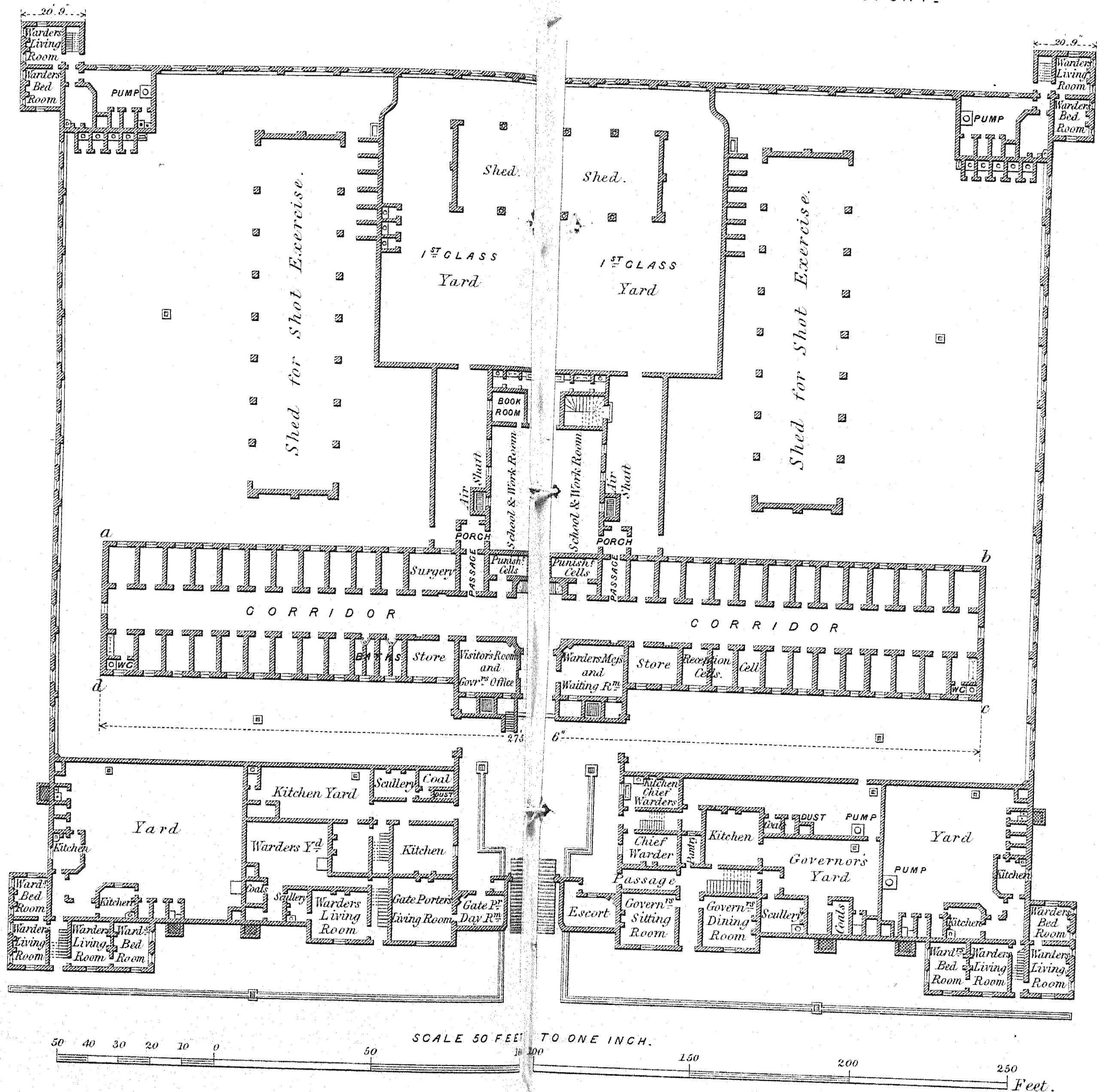
The building is constructed of brick, ornamented with stone coping; jambs and sills of windows of the same material. The roof is slated.

The cost was £26,735. 6*s*. 3*d*., being about £178 for each cell; and the prison is built for 150 prisoners upon the 'separate system.'

The offices, stores, kitchens, and quarters for the Governor and Warders, are shewn in Plate I.

Sheds for shot exercise and other punishments for the three classes are placed in the rear, on cast-iron pillars, with corrugated sheet-iron roof. See section to Plate II. —G. G. L.

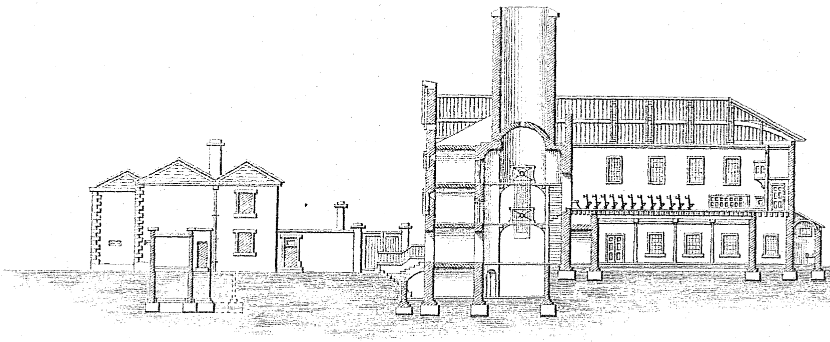
GROUND PLAN OF THE NEW MILITARY PRISON — GOSPORT.



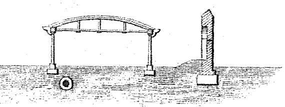
W. A. Beever, Sc.

London 1851

FORTON NEW MILITARY PRISON — COSPORT.

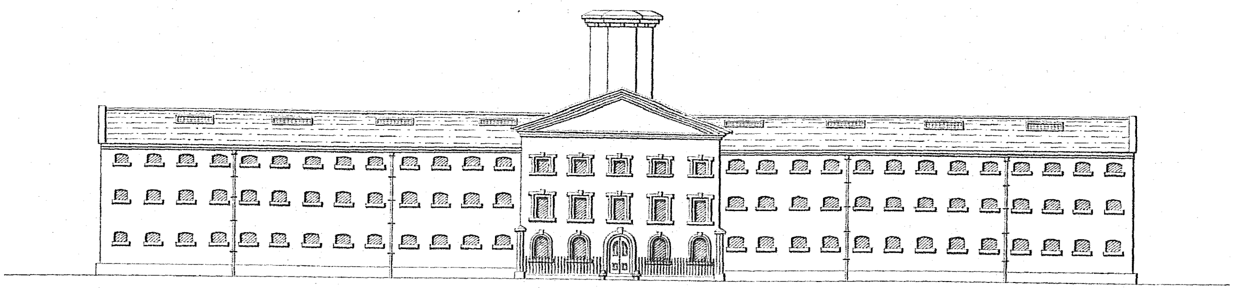


LONCITUDINAL SECTION OF CHAPEL.



Section of Roof for Shot Exercise.

FRONT ELEVATION.

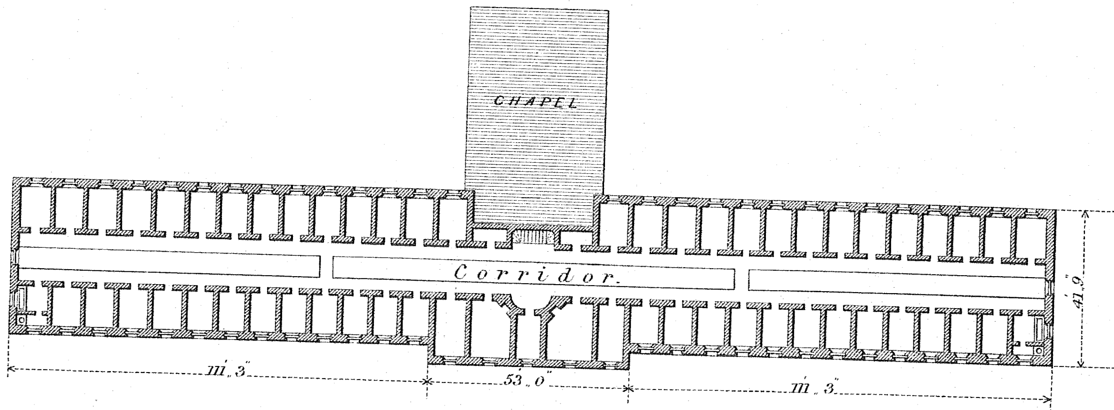


SCALE 50 FEET TO AN INCH.

Scale of 50 40 30 20 10 0 50 100 150 200 Feet.

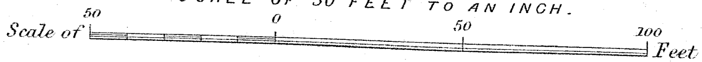
London, John Weale, 1851.

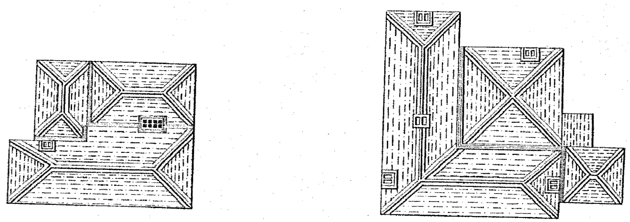
W. A. Beever. Sc.



PLAN OF 2^D & 3^D FLOORS.

SCALE OF 50 FEET TO AN INCH.





London. John Weale, 1851.

W. A. Beever, Sc.

PYROTECHNY, MILITARY.*

AMMUNITION.

Cannon Cartridges. Land and Sea Service.

The bags are made of serge, cut out and completed at the Laboratory for all the different natures of ordnance, according to the various calibres, their charges, and form of the chambers. They are filled by *weight*, choked, and having one or more bands, according to the dimensions of the cartridge, to add to its strength and security. Cannon cartridges vary in weight from 20 lbs. for the 68-pr. of 112 cwt. down to 6 ozs. for the 1-pr. brass gun amusette.

Fig. 1 represents a filled cartridge for 32-pr.

Fig. 2 represents a filled cartridge for 24-pr. howitzer.

Fig. 1.

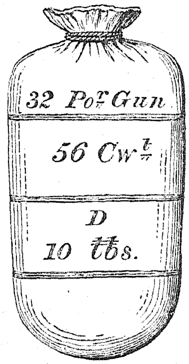
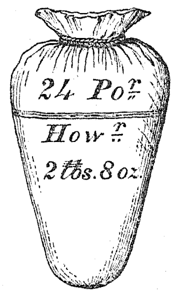


Fig. 2.



Filled cannon cartridges for Sailing Ships, stowed in metal-lined cases.

All filled cartridges supplied to Sailing Vessels of the Royal Navy are stowed in square wooden cases, copper-lined, the mouth of which is firmly secured with a luted bung, and again by the lid of the case, fastened with a metal key, and on the lid is marked its contents. These different cases are distinguished by *black letters*, when they contain the distant charges,—by *light blue* for the full charges, and by *red letters* for the reduced charges.

Fig. 3 represents a whole case, closed. Fig. 4, the same, open.

Fig. 5, the same, side view, shewing the rope-handles.

Fig. 3.

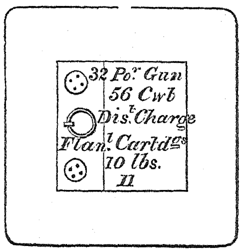


Fig. 4.

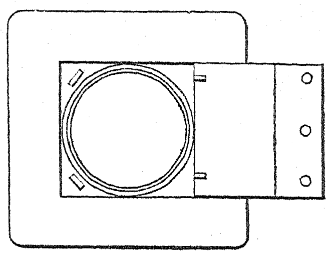


Fig. 5.

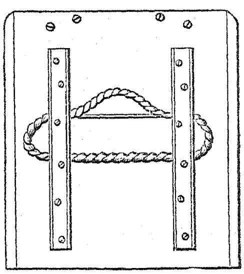


Fig. 6.

Bung.

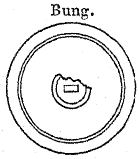
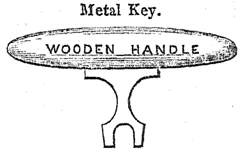


Fig. 7.

Metal Key.



* From the Royal Laboratory, Woolwich, by permission of Lieut.-Colonel Hardinge, Director of that Establishment.

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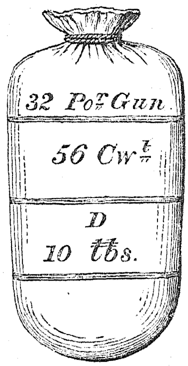
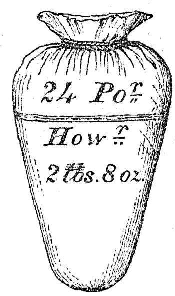


Fig. 2.



Filled cannon cartridges for Sailing Ships, stowed in metal-lined cases.

All filled cartridges supplied to Sailing Vessels of the Royal Navy are stowed in square wooden cases, copper-lined, the mouth of which is firmly secured with a luted bung, and again by the lid of the case, fastened with a metal key, and on the lid is marked its contents. These different cases are distinguished by *black letters*, when they contain the distant charges,—by *light blue* for the full charges, and by *red letters* for the reduced charges.

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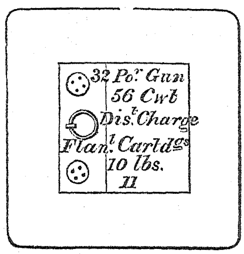


Fig. 4.

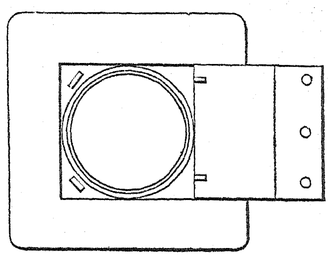


Fig. 5.

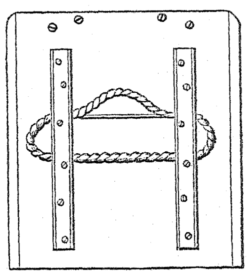


Fig. 6.

Bung.

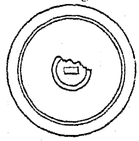
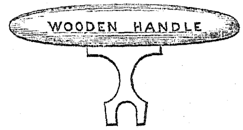


Fig. 7.

Metal Key.



* From the Royal Laboratory, Woolwich, by permission of Lieut.-Colonel Hardinge, Director of that Establishment.

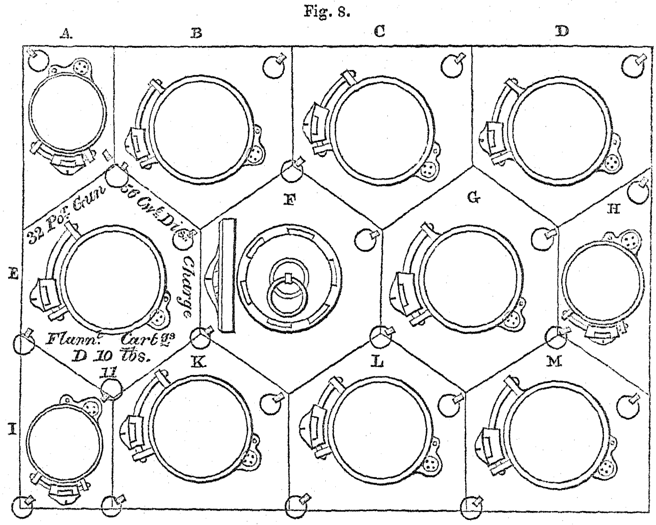
A whole case will stow 110 lbs. of powder in cartridges,—the half and quarter cases in proportion. Besides the cannon cartridges, all the small-arm ammunition and other combustible stores for Sea Service, such as blue lights, long lights, portfires, &c., &c., are packed in these different copper-lined cases. They are manufactured in the Royal Carriage Department, are very durable, and capable of standing much hard service, and generally repairable. The cost of a whole case is £1. 14*s.* 10*d.*

Filled cannon cartridges for Steamers, stowed in Dell's metal cases.

All filled cartridges for H. M. steamers are stowed in 'Dell's metal cases,' the mouth of which is similarly secured, and the lid marked with its contents, in colours, as on wood copper-lined cases. They are of hexagonal form; the number of filled cartridges they will contain is the same as the wooden cases, and, like them, they are also divided into whole, half, and quarter cases. There are also sectional cases, for the top tier, bottom, and sides.

The following is a representation of the mode of stowing the different metal cases in the magazines of H. M. steamers.

Fig. 8.



A, left sectional top.

B, C, D, top tier.

E, F, G, whole hexagon (F open, shewing the bung).

H, right sectional side.

I, left sectional bottom.

K, L, M, bottom tier. (The half and quarter cases are all hexagonal.)

Dell's cases are composed of a combination of metals, chiefly tin and copper. They are obtained by contract from the patentee at the price of 1*s.* 2*d.* per lb., or about £2. 18*s.* 4*d.* for a whole case. With fair usage and wear and tear, they are generally durable, and in most instances are repairable after long service at sea. They are considered to be best adapted for steamers, on account of economy in space.

Note.—All boat ammunition for steamers is stowed in metal-lined cases, the same as for sailing vessels.

Filled cannon cartridges for Land Service, stowed in ammunition boxes.

Filled cannon cartridges for Land Service are kept in the magazines, stowed in ammunition boxes. These cartridges are, however, generally limited in number, according to circumstances.

Empty cannon cartridge-bags, both for Land and Sea Service, packed in pressed bales.

Storekeepers and others in charge of magazines are supplied with cartridge-bags ready for filling when required. These empty bags are now sent to stations at home and abroad, and for both Land and Sea Service in pressed bales, containing numbers varying from 200 to 500 and upwards. A screw hand-press, capable of considerable power, is used for this operation. A covering of oil-cloth is also pressed over the bags, together with a stout canvas covering, well secured and marked.

Fig. 9 represents a bale of 500 24-pr. cartridge-bags, as packed for Land Service.

Fig. 10 represents a bale of 200 32-pr. cartridge-bags, as packed for Sea Service.

Fig. 9.

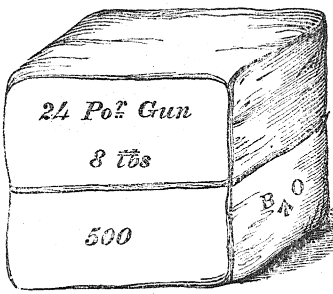
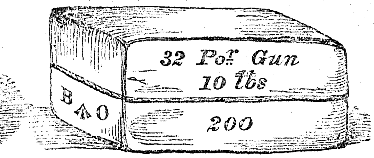


Fig. 10.



Note.—The close pressure of the bags, together with the covering of oil-cloth, is supposed to have the effect of arresting the destruction of moth. This mode of packing, however, has only been in practice about two years, and its advantages in that respect remain to be verified.

Small-arm cartridges, Land and Sea Service. Ball-cartridges.

To form the cartridges for the different natures of small-arm ammunition, the paper is cut accordingly: a former is then used, by first placing the ball in the cup at the bottom, and rolling the paper (white fine) tightly on to it, after which it is choked with a piece of catgut, fastened to the table for the purpose, and then tied close above and below the ball with two half-hitches and a thumb-hitch, and the end set down with the palm of the hand to form a good bottom, or, as it is termed, a 'rose.' The former is then withdrawn, and the cartridges placed upright in a box, in rows, for the purpose of filling. Rifle cartridges are formed with green paper, and without the ball attached, the latter being covered with a calico patch.

Blank cartridges.

Blank cartridges for all arms are made up in purple paper, and rolled together on the former in the same manner as ball.

Fig. 11, ball-cartridge former.

Fig. 11.

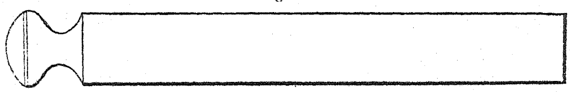
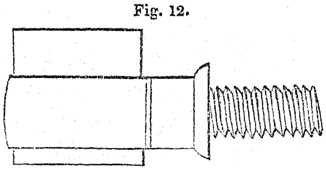


Fig. 12, choking knife, screwed into the table.

Fig. 12.

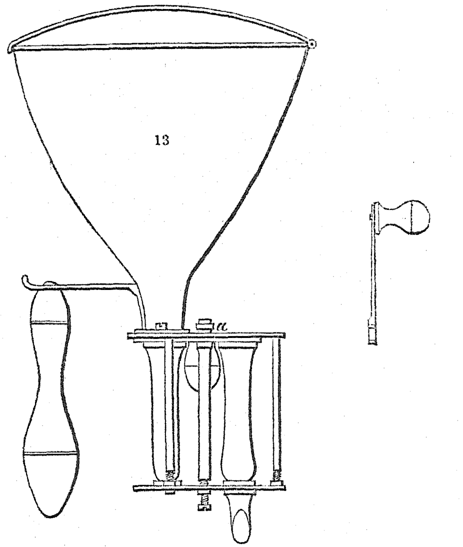


The cartridges, ball and blank, are filled by a machine, and after receiving the

proper charges are again choked by taking the open end between the finger and thumb of the left hand, and twisting the paper once round close to the powder, and tied with two half-hitches.

Cartridges, of all natures, are placed together in bundles containing 10 each: for ball-cartridges a slip of paper is used, the cartridge being placed with the balls end to end, over and under the slip; they are then packed in strong white wrapping paper, and tied across each way, and on which is printed the nature of cartridge and charge. Blank cartridges have no slips of paper between them, and are packed in purple paper, the same as the cartridges are formed with.

Fig. 13, machine for filling small-arm cartridges, with the lever or handle by which the measures are moved, and which is fixed at *a*.



The measures are fixed vertically in a circular plate, opposite to each other, with an axis between them, upon which they work between two other plates.

On the top of the plate a hopper is fixed, communicating alternately with the measures and filling them; and on the opposite side, in the bottom plate, is a hole with a spout, through which the discharge takes place. The plates are framed together by three pillars having double adjusting nuts on each, to regulate the distance of the plates.

The measures are moved by a handle or lever, the motion of which is limited by the pins, and which, while it presents one under the hopper to receive, places the other immediately over the discharging hole for delivery, so that the two operations of filling and discharging are going on at the same moment. The bottom of each measure is contracted, to retard, in a small degree, the discharge, so as to secure one measure to be filled before the other is emptied. A hole is cut in the top plate over the discharging measure, by which it may be ascertained that it is always full, as well as that the whole contents are delivered.

One boy can deliver with ease 12,500 measures daily from one machine, in the most accurate and perfect manner, and supplying his own hopper.

Note.—This ingenious little machine is the invention of Mr. Caffin, late Deputy Storekeeper, Royal Laboratory.

Table of the Weight of Bales, Powder, &c. for every nature of Small-arm Cartridges, Ball and Blank.

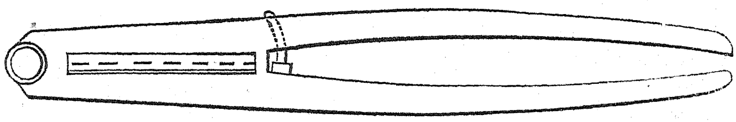
Nature of Cartridges.	Ball. Weight of Ball.	Ball. Weight of Powder.	Ball. No. of cartridges in each barrel.	Blank. Weight of powder.	Blank. No. of cartridges in each barrel.	Diameter of ball.	Diameter of former.	Remarks.
	In a lb.	drs.		drs.		inch.	inch.	
Wall-piece	7	10	300	6	600	·9	·84	Common, for flint locks.
Musket	14½	6	500	5	1500	·68	·65	
Carbine, M. B.	14½	5½	500	4½	1600	·68	·65	
Pistol, M. B.	14½	3½	700	3	2500	·68	·65	
Carbine	20	4	750	4	1800	·6	·59	
Rifle	20	4	750	4	1800	·6	·59	
Pistol, C. B.	20	3	750	3	2500	·6	·59	
Pistol	34	3	1000	3	2500	·51	·5	
Musket	14½	4½	500	3½	1800	·68	·65	Percussion.
Musket, Ordnance	14½	3½	600	3½	1800	·68	·65	
Victoria Carbine, M.B.	14½	2½	700	3½	1800	·68	·65	
Rifle Belted Ball, Infantry	12½	2½	600	3½	1800		·59	
Ditto, Naval	8	3½	Packed in copper-lined cases.				·65	
Carbine	20	2½	700	3½	1800	·6	·59	
Pistol	34	2	1000	2	2000	·51	·5	
Pistol, C. B.	20	2	800			·6	·59	

Note.—Ball-cartridges for all arms are packed in quarter-barrels, and blank cartridges in half-barrels. The corresponding number of copper caps, with 25 per cent. additional for the former, and 10 per cent. additional for the latter, are packed in zinc cylinders, placed in the centre of each barrel.

Ball, Lead (by casting).

The lead is melted in a large round iron pot, set in brickwork, and capable of containing 40 cwt. The lead is never to be made red-hot. With three moulds

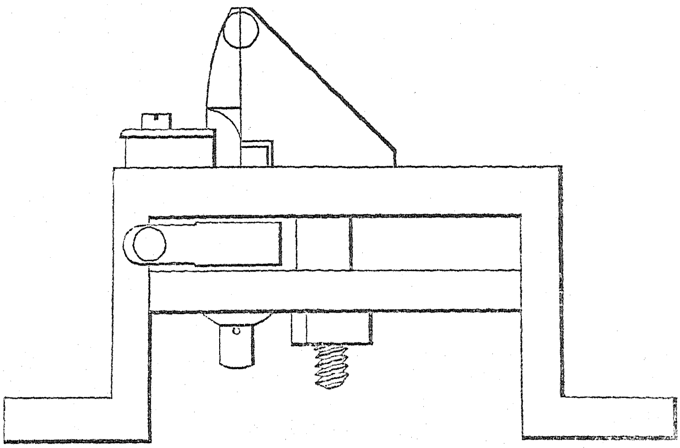
Fig. 14.—Ball or Bullet Mould.



and one ladle to each bench, the pot will employ three benches ; each bench employing two men, one casting, the other removing the balls from the moulds with a pair of pliers, and placing them in a box. The services of one man are also required to attend the fire. The men employed change about with every box they cast. A tub of water is kept under each bench, to cool the moulds; but in so doing, it must be particularly observed, that the moulds are only to be dipped into the water when the balls are in them, and also that they are kept tight, to prevent the water getting within, which would be dangerous to the men casting.

Note.—Two boys nip the same quantity as three men cast per day, and in this operation one boy cuts off the backs with the nipping machine (fig. 15), and the other afterwards examines the balls. These boys also change alternately.

Fig. 15.—Nipping Machine.



The bars of lead from which the balls are compressed are cast in moulds, 36 inches in length, and ·75 in diameter. These bars are then brought to the machinery, and are first passed through a roller, which condenses the lead, and prepares it for the second operation, that of compressing it into shape or form for the die. Thirdly comes the die, which by its regular movement forward is brought into contact with the masses of lead prepared, and as the die recedes, the boy moves up the bar for its next movement, and so on; following it up with other bars of lead arranged at his right hand, so that the die in its forward movement always finds its work prepared, and leaves the balls formed in a belt of lead. The fourth and last operation is that of cutting the balls out of the belt, which is done by a punch, exactly the diameter of the bullet, and which is brought over it and worked by a boy with his foot. The advantage of compressed over cast ball is its perfect solidity; whereas the cast has a flaw, more or less, in every bullet. The belted or rifle ball is, therefore, always made by compression.

Ball, Lead (by compression).

The machinery at present in use at the Royal Laboratory is the invention of Mr. George Napier, of Lambeth. There are two dies, altogether employing nine boys, and making 40,000 balls a day.

Note.—The power is derived from a small steam engine of Nasmyth's, which also works the machinery in the smiths' and turners' shops adjoining.

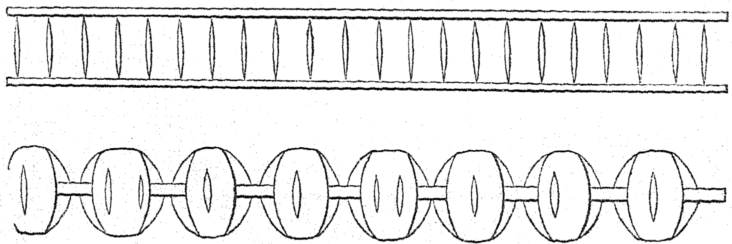
Fig. 16 shews the bar after passing through the roller.

Fig. 17, the same, formed into the masses.

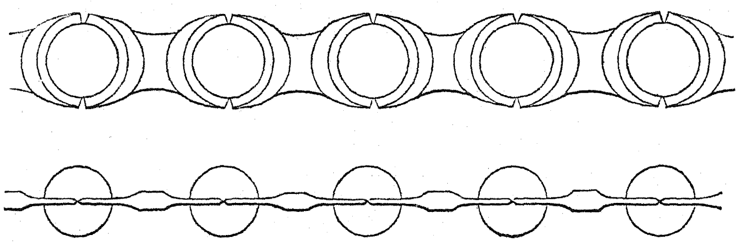
Fig. 18, the balls, as formed in the die.

Fig. 19 shews fig. 18 on both sides.

Figs. 16, 17.



Figs. 18, 19.



Balls, Light.

Light-balls are of four different natures, called 10-inch, 8-inch, 5½-inch, and 4⅖-inch. Their form is oblong. The skeletons are made of wrought iron, and are coated with canvas called Osnaburg, which is 24 inches wide. The canvas must be cut sufficiently long to wrap twice tightly round the skeleton, and stitched first up the seam, and then at the top and bottom of each bar, with a needle and twine, taking care to clip the canvas with a pair of scissors opposite each bar, and then turning in the cut part between the bars at the bottom, to prevent the composition coming out when the skeleton is being filled. Four holes are to be cut in the quarters for filling and priming.

Proportions of composition for light-balls.

	lbs.	oz.	drs.
Saltpetre, ground	6	4	0
Sulphur, "	2	8	0
Resin, pounded	1	14	0
Linseed Oil, boiled	0	7	8

The method of preparing the composition is the same as for carcasses.

Method of filling light-balls.

It must be observed, while filling, to press the composition well to the canvas, inside, to make it as round as possible, and after it is well filled, put in the wooden plugs for forming the priming-holes. These plugs must be well greased and fastened down, and the ball then put by to cool. They are next to be woolded with such sized quilting line as will admit of their passing freely through the gauge. The plugs are then taken out and the holes driven with fuze composition, the same as fuzes; and as the holes run the same size as the bores of fuzes, the same sized drifts will answer for driving them,—then primed with quick-match, and the holes covered with paper. The whole receives two coats of lead-coloured paint, and afterwards a barras cap, kitted and put over the top, and sprinkled with sawdust.

Table of the Weights of Oblong Light-Balls.

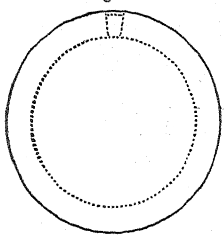
Nature.	Empty.		Coated.		Filled.		Woolded.		Primed.		Finished.	
	lbs.	oz.	lbs.	oz.	lbs.	oz.	lbs.	oz.	lbs.	oz.	lbs.	oz.
10-inch	33	0	33	10	68	14	69	8	70	4	71	2
8 "	15	12	16	1	32	14	33	2	33	10	34	0
5½ "	1	8	1	10	8	6	8	8	8	9	8	12
4⅖ "	1	2	1	4	4	9	4	11	4	12	4	14

Balls, Smoke.

Smoke-balls are of five different natures, viz. 13-inch, 10, 8, 5½, and 4⅖-inch. The cases are formed on a wooden ball, which is made of ash or other hard wood. This ball is to be well greased with tallow, to prevent the paper which is to form the skeleton from sticking to it. The paper is cut into strips about 3½ inches wide, and long enough to wrap once round the ball or former. These

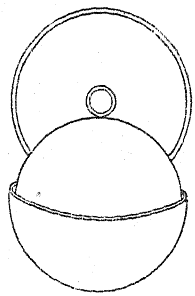
strips are put into water, and, when soaked a little, are to be taken out and pasted; one of these is then laid round the former, commencing at a certain point, and brought up to it on the other side. Both sides of the paper are to be notched with a pair of scissors, and the clipped parts laid regularly down, not allowing one of the pieces to lay over the other. Two round pieces of paper are then cut and pasted on each end; these must also be clipped, to make them lay close to the former. The first coat should only be slightly pasted; a second coat is then put on in the same manner as the first, except that the long slip is laid the contrary way. In this manner the ball is to receive four coats, laying the paper the contrary way each coat. It must then be left to dry, and when quite so, take a sharp knife and cut through it down to the wood, nearly all round, leaving about 1½ inch to form a hinge. The case is now to be opened by tapping it gently all over with a small mallet, and easing it with a knife until the former will come out. Strips of paper are then pasted over the joint, pressing it equally together. When it is perfectly dry, four more coats are put on as before, and so continued until the ball is brought up to the gauge. The fuze-hole is next bored with a Reimer, and then enlarged to the proper size with a round hot iron.

Fig. 20.



The paper shell complete.

Fig. 21.



The first four coats of paper cut through, to get out the former.

Table of the Dimensions of Formers and Wood Gauges for Smoke-Ball Cases.

Nature.	Diameter of the wood ball or former.	Thickness of paper complete.	Diameter of wood gauges.	Diameter of fuze-hole.	
				At top.	At bottom.
	Inches.	Inch.	Inches.	Inch.	Inch.
13-inch	11·3	1·45	12·75	1·837	1·696
10 "	8·6	1·15	9·75	1·57	1·45
8 "	6·65	1·1	7·75	1·325	1·227
5½ "	4·75	·79	5·54	·894	·826
4⅖ "	3·75	·65	4·4	·832	·769

Proportions of composition for smoke-balls.

	lbs.	oz.
Corned Powder, bruised	5	0
Saltpetre, pulverized	1	0
Sea-coal, pounded	1	8
Swedish Pitch	2	0
Tallow	0	8

Method of mixing the composition for smoke-balls.

The pitch and tallow is put into an iron pot, fitted into a copper, and filled with common sweet oil, which is made very hot: the saltpetre and sea-coal are then added. These ingredients, when well amalgamated, remain over the fire about a quarter of an hour: it is then transferred into a cooler pot, to prevent accident when

the powder is added. The whole is mixed well together. The composition is then taken out and placed upon a board to cool, and small portions at a time are taken in the hand to fill, and pressed in with a wooden drift. A wooden plug is put in for forming the priming-hole, and which must be well greased and tied down, to prevent the composition from forcing it out. When cold, the plug is taken out, and the hollow driven with fuze composition, and primed with quick-match, the same as a common fuze.

The following are the proportions of dry composition put into smoke-balls, for the purpose of occasionally clearing the vent:

For 13-inch	Sulphur . .	2 oz.	One of these proportions is put into the case each time, viz. when $\frac{1}{4}$ filled, $\frac{1}{2}$ filled, and $\frac{3}{4}$ filled, according to the nature of the smoke-ball.
	Sea-coal . .	2 „	
„ 10-inch	Sulphur . .	1 „	
	Sea-coal . .	1 „	
„ 8-inch	Sulphur . .	$\frac{1}{2}$ „	
	Sea-coal . .	$\frac{1}{2}$ „	

For the $5\frac{1}{2}$ and $4\frac{2}{5}$-inch, a small quantity of each put in twice is sufficient.

Smoke-balls have lastly three coats of lead-coloured paint on the outside.

ps, Copper. All copper caps for the service of the Army and Navy are manufactured at the Royal Laboratory, and are of one pattern only for every nature of small-arm. The Government caps differ in make and form from those of general manufacturers. There is more copper in them, having a flange or rim, for the purpose of giving a firmer hold to those using them: a more extensive process is also adopted, to secure the composition from deterioration, either from damp magazines or the effects of climate, to which the caps are exposed in every part of the globe.

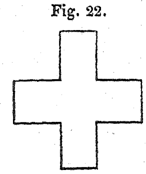
The mode of manufacture of copper caps is expeditious, although passing through many hands before it is accomplished, and is as follows:

1. The sheets of copper are cut into slips, 24 inches long and $3\frac{1}{4}$ inches wide.

2. These slips are passed between a roller, which operation smooths the copper and brings it to a uniform thickness.

3. The slips are cut into crosses, $\frac{3}{4}$ of an inch in diameter, each slip producing 130 crosses.

Fig. 22.



4. The crosses are placed in an iron cylinder, and made red-hot in a furnace, for the purpose of annealing the copper, thereby rendering it less brittle for the die.

5. The crosses are next pickled in dilute sulphuric acid, to clean them from the effects of the fire.

6. They are dried by being shook in a bag containing sawdust.

7. They are oiled in what is termed a drum.

8. The crosses in this state are put into the die, forming the cap, which, at the same time, affixes the Government mark on every cap.

9. The caps are then shook in a bag of sawdust, to be cleaned of the oil.

10. They are then arranged in a brass plate for loading, and which plate contains 1000 caps.

11. The plate of 1000 caps is then passed to the loading machine to receive the charge, which consists of proportions of the fulminate of mercury and chlorate of potassa, with a very small quantity of finely-powdered glass.

12. The detonating composition is next pressed firm into the caps by a machine.

13. The composition in each cap receives a coating of varnish, consisting of a mixture of shell-lac and spirits of wine. This varnish affords great security in resisting damp and the effects of climate, and fixes the composition firmly in the cap.

14. The caps are placed upon a steam-bath, to dry and harden the varnish.

15. They are glazed by applying a steel burnisher to the composition of every cap, separately; the friction and pressure of this burnisher, turned in a lathe, producing a very hard and glassy surface.

16. The caps are once more shook in a bag containing very fine sawdust, to render them perfectly bright, and are then ready to be packed for service.

Copper caps for the Land Service are first packed in parcels of 25 each (the proportion for 20 rounds of ball-cartridges). Three of these parcels are then placed into one, making the due proportion of caps for 60 rounds of ball, and are thus stowed in zinc cylinders with the ammunition. Blank cartridges have 22 caps similarly packed for 20 rounds, and 66 caps for 60 rounds.

Copper caps for the Naval Service are placed in stone jars, glazed within and without, and secured at the mouth with a covering of India-rubber, each jar containing 1000 loose caps.

Note.—The presses and other machines at the Royal Laboratory, when in full work, are capable of manufacturing 200,000 caps a day; but 40,000 to 50,000 a day form the usual ordinary work, to meet all demands.

The machines are all worked by hand, and boys only are employed.

Carcasses.

Carcasses for Land and Sea Service are of eight different natures, viz. 13-inch, 10, 8, 5½, and 4⅖-inch; 42-pr., 32-pr. and 18-pr. The skeletons or cases are similar to common shells, but with three and four fuze-holes, and the ingredients for filling as follows:

Proportions of composition for carcasses.

	lbs.	oz.
Saltpetre, ground	6	4
Sulphur, ditto	2	8
Resin, pounded	1	14
Antimony, ditto	0	10
Tallow	0	10
Venice Turpentine	0	10

Method of mixing the composition for carcasses.

The dry ingredients are all well mixed together with a copper slice, and afterwards passed twice through a fine hair sieve. The turpentine and tallow are put together into an iron pot (which fits into a copper containing about 27 gallons of oil), to be well melted; the dry ingredients are then added, stirring with an iron paddle for 15 or 20 minutes, until the sulphur begins to run. The whole is then taken out of the pot with a ladle, a little at a time, and laid to cool on the lead covering of the copper. Before the filling is commenced, corks are driven into all the holes except one. The carcasses are then filled by forcing in the composition with a wooden drift through a tin funnel, taking great care that it is filled solid: the corks are next taken out, and priming-plugs, well greased, are forced in and fastened down until the composition is quite cold. These plugs are then withdrawn, and all the holes driven with fuze composition and primed with quick-match, the same as common fuzes. Lastly, a barras cap, kitted and cut larger than the holes, is laid on and sprinkled with sawdust.

Table of the Weights of Round Iron Carcasses.

Natures.	Empty.				Weight of composition.		Total weight.			
	cwt.	qrs.	lbs.	oz.	lbs.	oz.	cwt.	qrs.	lbs.	oz.
13-inch	1	2	27	0	17	14	1	3	16	14
11½ „	1	1	3	8	10	8	1	1	14	0
10 „	0	3	6	4	7	4	0	3	13	8
8 „	0	1	20	0	2	14	0	1	22	14
5½ „	0	0	15	6	1	3½	0	0	16	9½
4⅖ „	0	0	8	6	0	7	0	0	8	13
42-pr.	0	1	0	14	1	12	0	1	2	10
32 „	0	0	23	3½	1	4½	0	0	24	8
18 „	0	0	13	12	0	11	0	0	14	7

Fuzes, Wood.

Wooden fuzes are of seven different natures, viz. 13-inch, 10, 8, $5\frac{1}{2}$, and $4\frac{2}{5}$-inch, adapted for common shells and hand-grenades, and 8 and $5\frac{1}{2}$-inch for spherical.

Dimensions of empty fuzes.

They are of the following dimensions:

Nature.	Total Length.	Exterior Diameter.		Cup.		Bore.		Length of solid bottom.
		Top.	Bottom.	Diam.	Depth.	Diam.	Length.	
	inches.	inches.	inch.	inch.	inch.	inch.	inch.	inch.
13-inch	10·55	2·48	1·66	1·49	·75	·525	8·5	1·25
10	9·3	2·14	1·4	1·28	·7	·45	7·47	1·13
8	8	1·79	1·16	1·07	·56	·375	6·59	·85
$5\frac{1}{2}$	5·6	1·3	·9	·78	·43	·275	4·49	·65
$4\frac{2}{5}$	4·6	1·18	·82	·71	·41	·25	3·5	·62
spherical 8	2·7	1·33	1·03	·9	·25	·375	1·77	·7
spherical $5\frac{1}{2}$	2·5	·94	·72	·7	·25	·275	1·77	·5

The 13-inch fuzes are graduated to 8 inches; the 10 to 7 inches; the 8 to 6 inches; the $5\frac{1}{2}$ to 4 inches; and the $4\frac{2}{5}$ to 3 inches, and subdivided into ·2. The 8 and $5\frac{1}{2}$-inch spherical are graduated to 1 inch, and also subdivided into ·2. These fuzes are driven with fuze composition, one inch of which must burn five seconds, neither more nor less, or the calculation for firing shells would be rendered useless.

Proportions of fuze composition.

Saltpetre, pulverized	3 lbs. 4 oz.
Sulphur, sublimed	1 lb.
Pit-mealed Powder	2 lbs. 12 oz.

Method of mixing the composition.

The above-named ingredients are mixed well together by a copper slice, and then passed through a fine hair sieve three times, and afterwards through a lawn sieve. It is then to be well rubbed with the hands, and with a copper shovel put into the composition tub.

Observations.

It is to be observed, that unless the composition is well mixed, it will not answer for fuzes, as their efficiency depends upon the manner of mixing and driving the composition; and no other powder will answer for fuze composition but that which is made of pit charcoal; also, that for all composition in which charcoal and mealed powder form a part, the sieve in which it is mixed must have a top and bottom, to prevent the finer particles from flying about, which would not only be disagreeable to the mixer, but would rob the composition of its strength.

Method of driving fuzes.

The fuze is placed into the socket, of which there are several sizes, placed upon a block, according to the nature of each. Turn in a ladleful of composition, taking care to strike it off level, and, with the longest drift and mallet, of the same nature, give it the regulated number of blows, and so continue until the second drift will reach the composition: continue driving with that drift until within about one ladleful of the top, which space is left for the priming of the quick-match. After they are driven, they are marked with the composition gauge, to ascertain the height of the composition.

Method of priming fuzes.

The fuze is placed into the socket, and a little of the composition on the top loosened with a pricker. The quick-match is cut to the proper length required, doubled, and put into the centre of the cup with a mallet and drift, then a ladleful of pit-mealed powder, and driven in the same manner as a fuze, so as to be firm enough to lift the fuze out of the socket; and the ends of the quick-match are laid inside the cup. Lastly, a mixture of mealed powder and spirits of wine is laid over the match, and the top dipped into mealed powder, and then the fuze is set aside to dry.

Method of capping fuzes.

A circle of strong cartridge paper is cut to the size of the fuze and laid on the cup, then a square piece of fine canvas or duck over it, and tied with packing twine. The canvas below the twine is cut off, leaving about two-tenths of an inch to be turned back, to prevent the twine from slipping off.

Fuzes, Metal (Naval Service).

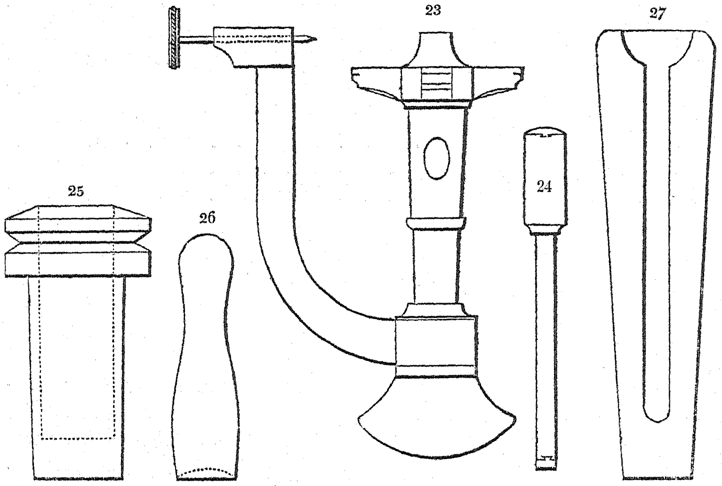
Metal fuzes are of three natures, viz. 3-inch, 4-inch, and short-range fuzes. The first is driven with mealed powder, and will burn seven seconds; the second is driven with fuze composition, and will burn twenty seconds; and the short-range fuze is also driven with composition, and will burn two seconds.

These fuzes are driven and primed precisely the same as wooden fuzes, but, instead of being capped with canvas, have a screw metal cap.

The fuzes are screwed into the shells, the holes of which are bouched with metal to receive them; they are screwed in to the left hand, so that unscrewing the cap in the same direction prevents the possibility of the fuze being loosened by that operation.

Note.—The diameter of the fuze-holes for all natures of shells fitted to receive metal fuzes is precisely the same.

23. Composition gauge.
24. Iron drift, tipped with brass.
25. Socket.
26. Setter.
27. Section of common fuze.



Lights, Blue.

The following is the composition for blue lights:

Saltpetre, ground	7 lbs.
Sulphur, do.	8 oz.
Red Orpiment	8 oz.

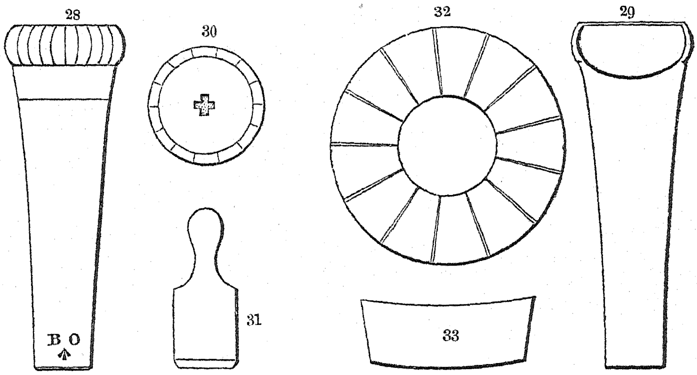
Method of mixing the composition.

The above ingredients, having been carefully weighed, are placed on a table and well rubbed with a copper slice, and passed three times through a fine hair sieve: any portion not passing through must be again rubbed until sufficiently fine to do so. The cup is well filled with the composition by rubbing it in hard with a small wooden slice; a piece of small-arm cartridge-paper, about 4 inches square, is pierced with four holes towards the centre, and two pieces of quick-match, $2\frac{1}{2}$ inches in length, are placed across each other. This paper is placed over the cup with the quick-match next to the composition; another covering of plain paper is then put over it, and the two are choked, and tied with two half-hitches and a thumb-hitch of fine twine round the groove: the paper is then cut off all round, a quarter of an inch below where it was tied; a circle of wrapping paper, 5 inches in diameter, is clipped to within 2 inches of the centre, pasted and put over the cup, and the

clipped parts neatly laid round. Lastly, two bands of the same paper, 1¼ inch wide, are pasted over all. The blue lights are then placed in boxes to dry.

Note.—A blue light will burn about half a minute.

28. Blue light complete.
29. Section.
30. Plan with quick-match.
31. Slice.
32. Paper circle.
33. Paper band.



Lights, Long, or Stevens's.

The composition for long or Stevens's lights is precisely the same as that for blue lights.

The cases are made of brown paper, slightly pasted and rolled on a wooden former, in the same manner as common portfire cases: they are made to the same diameter as the 1-℔. signal rocket, the same cylinder-gauge being used for them. The case is cut to the length of 9·75 inches, one end of which is perforated at an inch from the bottom, to allow a wooden pin to pass through it, for the purpose of attaching the handle to the case.

Method of driving long lights.

Long lights are driven on a wooden nipple, 2 inches in length, and of the same diameter as the cylinder former for the 1-℔. signal rockets. A circle of cured paper, of the same diameter as the interior of the case, is placed on the nipple, and a ladleful of clay driven hard upon it; then a ladleful of composition is put in, and fifteen very light blows given with an 8-inch fuze mallet. The composition is continued to be driven in this manner till the case is quite full, when it is taken off the nipple, and primed in the same way as blue lights. They afterwards receive two coats of paint. A long light will burn five minutes.

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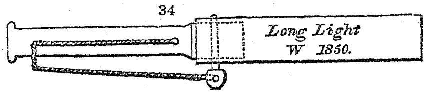


Note.—The ladle used in driving is the same as that for 1-℔. signal rockets.

Match, Quick.

The following are the proportions of composition, &c., for quick-match:

Cotton	1 ℔. 12 oz.
Saltpetre, pulverized	1 ℔. 8 oz.
Cylinder-mealed Powder	10 ℔s. 0 oz.
Spirits of Wine	2 quarts.
Water	4 quarts.

Method of mixing the composition for quick-match.

The saltpetre is put into a pan and the end of the wick secured to one of the handles to unwind the cotton from the bale; the last end is fastened to the other handle of the pan; the water is then poured upon the cotton and saltpetre, and the pan placed over a clear charcoal fire and boiled gently for about ten minutes; the spirits of wine is next added, and the whole allowed to boil ten minutes longer:

afterwards the pan is taken from the fire and dipped into cold water, to prevent any accident which might arise from coals or other matter adhering to it; it is then taken to another room and covered with one-third of the mealed powder, and so left for about six hours to get well soaked: the last end of the wick is then secured to one of the handles of another pan, and the wick drawn gently through the hand into it, taking care that no part of the cotton passes uncovered. The second portion of the mealed powder is then added, and the liquid in the first pan poured upon it, and left to stand the same time as before. One end of the wick is next fastened to the reel, and wound on to it tight. When the whole is wound out of the pan, the reel is taken off the stand, and laid on two battens on the table. Next sift half the remaining powder equally over the upper side, and turning the reeling frame, sift the rest over that side. The match is then set aside to dry.

Match, Slow.

Slow-match is merely hempen rope loosely twisted and dipped in a solution of saltpetre and lime-water.

Note.—A yard of slow-match will burn about three hours.

Portfires, Common.

Portfires are of four different natures, viz. Common Portfires, Percussion Portfires, Miners' Portfires, and Slow Portfires.

Method of making the cases for common portfires.

One-third of the sheet of paper used for this purpose is cut off lengthwise, and the whole is pasted thinly all over; the part cut off is then placed on the centre of the remaining two-thirds, and with the iron former, well pasted, is rolled on it upon a board for the purpose: when supposed to be sufficiently rolled, it is tried with a gauge 7-10ths of an inch in diameter, adding or reducing the paper accordingly. The former is next taken out, and the case laid to dry.

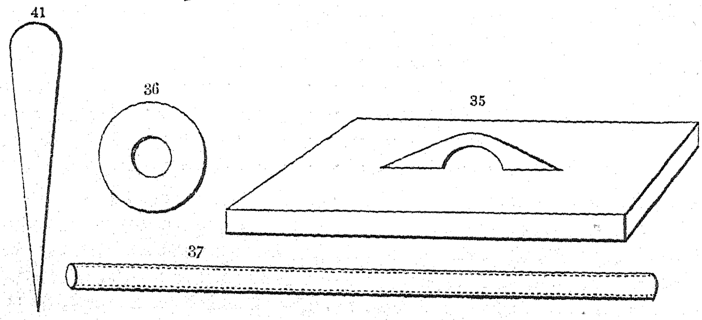
Proportions of composition for common portfires.

Brimstone, sublimed	. . . .	2 lbs.
Powder, cylinder-mealed	. . . .	1 „
Saltpetre, pulverized	. . . .	6 „

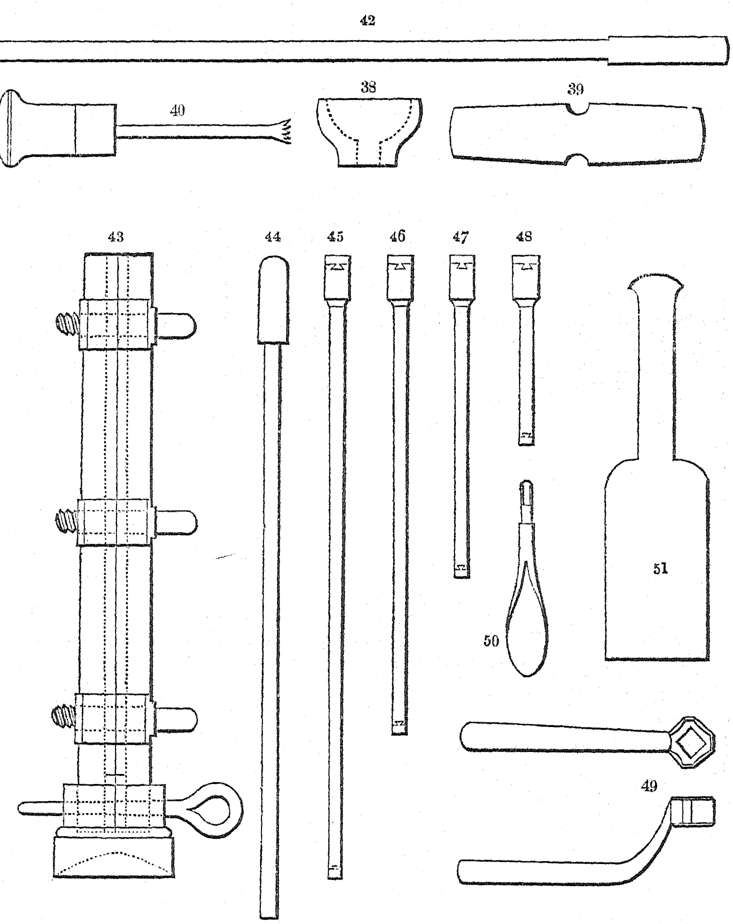
Method of driving common portfires.

The case being thoroughly dry, the bottom is turned in with a brass pricker, to form a good bottom. It is then placed in the mould with the setting drift in it, and which is driven to the bottom of the case with a few blows of the mallet; the mould is then screwed up tight, and the drift taken out. A wooden cup, to prevent waste of the composition, is placed on the mouth of the case, above the top of the mould, and the case is cut off level with the inside of the cup, and opened with a wooden fid, to admit the drift. Commence driving by taking a ladleful of composition and the longest drift, giving it fifteen blows with a 10-inch fuze mallet: when the composition is high enough, the second drift is used, and afterwards the third and fourth. When the portfire is driven, the cup is taken off, and the case cut off level with the mould. Portfires are primed with mealed powder and spirits of wine, and receive two coats of paint before they are issued for service.

Note.—A common portfire will burn fifteen minutes.



35. Rolling board.
36. Gauge.
37. Empty case.



8. Wooden cup.
9. Handle for bridle.
0. Brass pricker.
1. Fid.
2. Iron former.
3. Mould.
4. Setting drift.
5. First drift, tipped with brass.
6. Second do.
7. Third do.
8. Fourth do.
9. Wrench.
0. Ladle.
1. Mallet.

Portfires, Percussion.

The cases are made of signal-rocket paper, folded and cut in the same manner as for ½-lb. signal rockets. The paper is thinly pasted all over and rolled on a former; it is then taken off the former and dried, and one end turned in to form the bottom, and afterwards cut to the length of 10¾ inches. The collars and caps are made of the same kind of paper as the cases, and rolled on a wooden former 1·3 inch in diameter, and brought up to the 1-lb. signal rocket cylinder-gauge. The piece formed for the cap is choked at one end, tied with Dutch thread, and trimmed with a sharp knife to form a neat rose. On the top it is cut to the length of 2·8 inches: the collars are of the same diameter, and cut to three-quarters of an inch long.

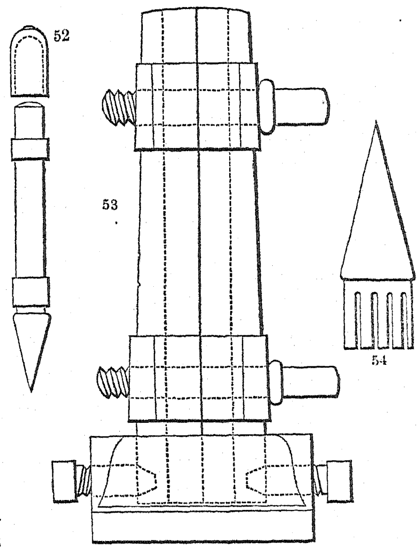
Proportions of composition for percussion portfires.

Brimstone, sublimed	4 lbs.
Powder, mealed cylinder	1 „
Saltpetre, pulverized	8 „

Method of driving percussion portfires.

These portfires are driven in a ½-lb. signal-rocket mould, having two screws at the

bottom to secure it; eighteen blows are given to each ladleful of composition with a pound signal-rocket mallet. When the composition is within half an inch of the top of the case, the portfire is taken out of the mould and cut to the length of $9\frac{1}{2}$ inches. The edge of the case is trimmed a little lower than the composition, so as to form a round top. A tin point or cone, filled with resin, is fitted to the bottom or turned-in end, moulding the clipped parts over with kitted twine, and pasting a slip of fine white paper over it: the collar is glued on at the mark made by the gauge. When dry, the paper cap is fitted on, and they receive two coats of paint.



52. Portfire complete.
53. Mould.
54. Tin point.

The percussion priming is added to these portfires at the stations where they are used (principally for the Coast-Guard), and is simply a small glass globule containing sulphuric acid. This is imbedded in loose composition, which ignites on the globule being broken.

Note.—A percussion portfire will burn five minutes.

Portfires, Miners'.

The cases are made of white fine paper by cutting the sheet into six equal parts; one of these parts is thinly pasted about $\frac{3}{8}$ths of an inch on one edge, and rolled tightly on an iron former: when this is sufficiently done, they are laid to dry, previous to filling.

Proportion of composition for miners' portfires.

Saltpetre, pulverized	8 oz.
Sulphur, sublimed	8 „
Powder, cylinder-mealed	1 ℔.

The method of filling miners' portfires.

A copper funnel is placed in the mouth of the case, turning in the other end to form a bottom. Fill the funnel full of composition, and put the drift through into the case, keeping it moving till it is nearly full. These cases may be joined together, to make any length required, by cutting off the end that was turned in, and placing it in the mouth or open end of another case, and securing it with a piece of Dutch thread.

Miners' portfires are packed for store in brown-paper parcels containing 100 each.

Portfires, Slow.

Method of rolling the paper for slow portfires.

The paper, which is called blue sugar-loaf paper, is wetted by dissolving 12 ounces of saltpetre in one gallon of water; each sheet is wetted separately on both sides with a brush, one side being dried before the other is made wet: when both sides are thoroughly dry, they are to be well rolled with a rolling board until they are hard and solid; the outer edge is then pasted and laid closely down. In rolling these portfires, one end should be formed conical, and the other cut off fair to the length of 19 inches.

Slow portfires burn from three to four hours each.

Rockets, Congreve.

Congreve rockets are of four different natures, viz. 24-pr., 12, 6, and 3-prs. The cases are made at the Laboratory, of wrought iron, and although upon a much larger scale, are driven upon the same principle as signal rockets. The power is given by

the fall of what is termed a monkey, the weight of which is in proportion to the nature of the rocket to be driven.

Congreve rockets may be used either as shot or shell rockets, and the shell made to burst either at long or short ranges, as required. Every rocket is fitted with a fuze screwed into the base of the shell; this fuze is as long as the size of the shell will admit of, so as to leave sufficient space between the end of it and the inner surface of the shell, for putting in the bursting powder; and the end of the fuze is cupped, to serve as a guide in the insertion of the boring-bit. There is a hole in the apex of the shell, secured by a screw metal plug, for putting in the bursting powder and for boring, according to the different ranges at which it may be required to burst the shell.

The following stores and implements form part of the present Rocket Equipments:

Bursting powder, fine-grain, made up in bags, and marked according to the nature of the rocket.

Funnels for loading the shells.

Boring stocks or braces.

Boring-bits, of the same diameter as the fuze composition, fitted with brass graduated scales, and of a length sufficient to bore to within 1½ inch of the top of the cone in the 24-pr. rocket, and to within 1 inch of the top of the cone in the 12, 6, and 3-prs.

Turnscrew-bit for the plug.

Grease for the boring-bits.

In Field Service, the bursters are carried in the limber boxes, in canvas cartouches similar to those in which the field ammunition is carried, and the small stores in a box on the body of a carriage opposite, and corresponding to the slow-match box.

For Her Majesty's Ships of War the bursters are issued in the metal-lined cases of the Service, and the small stores in a box made for the purpose.

For Garrisons or other occasional demands, the bursters are issued in the packing cases now in the Service, and the small stores in a box made for the purpose.

General observations on firing rockets.

If the rocket is to be used as a shot rocket, the only thing to be attended to is to take care that there is no powder in the shell, and that the plug is secured in the plug-hole. If the rocket is to be used as a shell rocket at the longest range, the plug is to be taken out and the shell filled, the fuze left at its full length, and the plug replaced.

If at the shortest range, the fuze is to be entirely bored through, and the rocket composition bored into, to within 1½ inch of the top of the cone in the 24-pr. rocket, and to within 1 inch in the 12, 6, and 3-pr. rockets. The distances from the surface of the shell to the top of the cone, and from the surface of the shell to the end of the fuze, and also the length of the fuze, being fixed and known, the place on the boring-bit at which to screw the stopper, whether for various lengths of fuzes, or lengths of rocket composition to be left over the cone, is easily determined: these distances are marked on the brass scales for each nature of rocket; and the length of rocket composition available for boring into, and the lengths of fuze, are also set off and subdivided into tenths of an inch.

General observations on elevations, ranges, and lengths of fuze.

24-Pounders.—If the whole length of the fuze is left in the shell of the 24-pr. rocket, it may be expected to burst at about 3300 yards; elevation 47 degrees.

If the whole of the fuze composition is bored out, and the rocket composition left entire, the shell may be expected to burst at about 2000 yards; elevation 27 degrees.

If the rocket composition is bored into, to within 1·5 inch of the top of the cone, the shell may be expected to burst at about 700 yards; elevation 17 degrees.

12-Pounders.—If the whole length of fuze is left in the shell of the 12-pr. rocket, it may be expected to burst at about 3000 yards; elevation 40 degrees.

If the whole of the fuze composition is bored out, and the rocket composition left entire, the shell may be expected to burst at about 1300 yards; elevation 20 degrees.

If the rocket composition is bored into, to within 1 inch of the top of the cone, the shell may be expected to burst at about 500 yards; 10 degrees' elevation.

6-*Pounders.*—If the whole length of fuze is left in the shell of the 6-pr. rocket, it may be expected to burst at about 2300 yards; 37 degrees' elevation.

If the whole of the fuze composition is bored out, and the rocket composition is left entire, the shell may be expected to burst at about 950 yards; elevation 15 degrees.

If the rocket composition is bored into, to within 1 inch of the top of the cone, the shell may be expected to burst at about 500 yards; elevation 10 degrees.

3-*Pounders.*—If the whole length of the fuze is left in the shell of the 3-pr. rocket, it may be expected to burst at about 1850 yards; elevation 25 degrees.

If the whole of the fuze composition is bored out, and the rocket composition is left entire, the shell may be expected to burst at about 750 yards; elevation 12 degrees.

If the rocket composition is bored into, to within 1 inch of the top of the cone, the shell may be expected to burst at about 500 yards; elevation 8 degrees.

Rockets, Signal.

Method of making cases for signal rockets.

Signal rockets are of two natures, viz. 1-℔. and ½-℔. rockets. The cases are made of sheets of strong paper, which are 2 feet 5 inches in length and 1 foot 11 inches in width. They are turned upon a brass turner by taking one turn round it, and keeping the paper very tight with the left hand; it is then pasted thinly within 3 or 4 inches, and rolled up. The case is next taken to a press and rolled, by turning it round lightly at first, until it is set to the former. A weight is put on the press, and the former turned by the handle until it is of proper size to admit the case passing through the cylinder-gauge, adding or reducing the paper as required. It is then removed from the former to be choked, which is done by placing the hide round it, close up to the cylinder-gauge, and pressing the treadle with the foot, working the case at the same time. It is then tied tight with six or seven half-hitches of packthread. Slip the gauge to the bottom of the case, and set the choke on a nipple by putting in the setting stick, and giving it eight or nine blows with a mallet. It is then marked with a gauge to the length it is to be cut, and, when sufficiently dry, the case is ready for driving.

The process for forming all signal-rocket cases is precisely similar to each other, except in the weight used upon the press, which is 1 cwt. for the 1-℔. rocket, and ½ cwt. for the ½-℔. rocket. (See figs. 55 to 62.)

Proportions of composition for signal rockets.

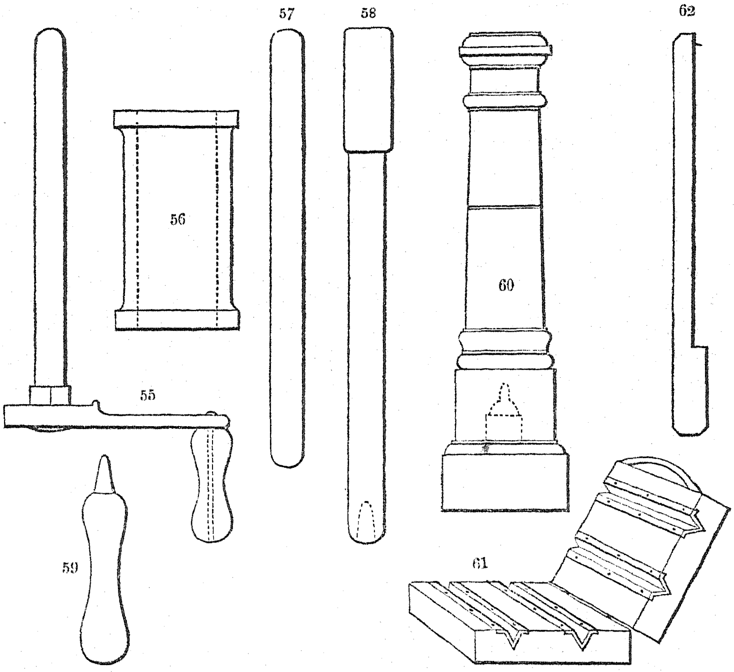
Saltpetre, pulverized	4 ℔s.
Sulphur, sublimed	1 ℔.
Dog-wood charcoal	1 ℔. 8 oz.

Method of mixing the composition.

The charcoal is placed on a tray lined with copper, and rolled with a gun-metal roller until it is fine enough to pass through a wire sieve, 17 meshes to the inch. The saltpetre and sulphur are put in a mixing tray, and well amalgamated with a copper slice, and then passed through a fine hair sieve. The portion of charcoal is next spread thinly over the tray, and the other ingredients sifted over it, the whole being well mixed together with the hands. It is then passed four times through the wire sieve, and any portion not passing must again be rubbed sufficiently fine to do so. It is then taken up with a copper shovel, and put into the composition box ready for use.

Method of driving signal rockets.

The slip-gauge is first put down to the bottom of the case, which is marked with a pricker through the hole in the gauge, on the exterior of the case; the diameter-gauge is then taken, and the bottom pin placed in the hole made by the pricker: the pin, being tapped with a mallet, will leave an impression on the case (the 3½ diameter



55. Brass former.
56. Cylinder-gauge.
57. Cutting stick.
58. Nipple former.
59. Nipple.
60. Setting mould.
61. Press.
62. Length-gauge.

mark being the length of the spindle). From the $3\frac{1}{2}$ diameter to the $4\frac{1}{2}$ solid,—from the $4\frac{1}{2}$ solid, $\frac{1}{5}$ of a diameter, clay is driven in the same way.

The setting drift is then inserted, and the case beat with a light mallet to remove the paste from the surface, previous to moulding. The case is placed in the mould, and set on the spindle, replacing the setting drift, and giving it a few blows with the mallet. The mould is screwed tight, and the driving commenced by taking a ladleful of composition from the box, and striking it off level with the bar across the box, for the purpose. On turning it into the case, take the longest hollow drift, and with the mallet give it the regulated number of blows, viz. 25 blows for each ladleful for the 1-lb. rocket and 21 blows for the $\frac{1}{2}$-lb. rocket, moving the drift at every blow. The driving is continued by putting in a fresh ladleful, and repeating the number of blows until the second hollow drift reaches the face of the composition, taking care, in again driving, to clear out the drift every time of putting in fresh composition. When the latter is high enough, take the next drift, and so continue until the spindle is covered, which is known by putting in a copper scoop; and if the spindle is not felt, the solid drift is taken till the composition has reached the $4\frac{1}{2}$ diameter mark. If the composition is to its height, put in a ladleful of clay, and give it the same number of blows as are required for the composition. For the 1-lb. rockets, four drifts are used, and for the $\frac{1}{2}$-lb. rockets, three drifts.

The rocket is then unmoulded by loosening the screws and taking out the pin. Place the bridle on the case, turning it to the right, to prevent unscrewing the spindle: the rocket is then ready for finishing.

Method of making cylinder and projecting heads for signal rockets.

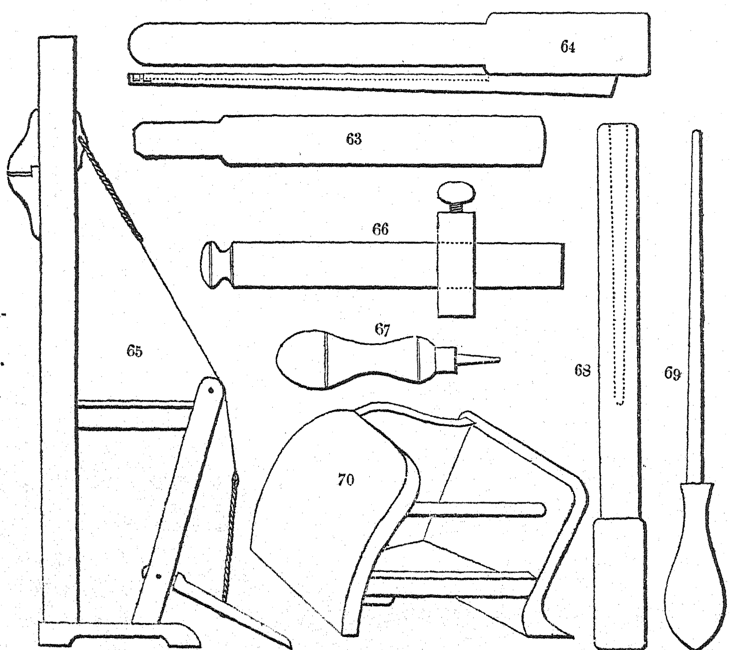
The paper is cut to the proper size and shape, and for the projecting heads there are two papers: one is signal-rocket paper, soaked in water and pasted. The rocket ring being placed on the former, the paper is wrapped round it, and choked with

Dutch thread in the groove of the ring. The other paper, which is wrapping paper, is cut longer and pasted on, and, when dry, notched round the top to cover the stars. The cylinder heads are made of rocket paper, all in one piece, passing twice round the former, and having four strips cut in the part which first passes round it; then pasted and rolled, and, when dry, notched in the same way as the projecting heads. For making the cones, cut out half a circle of rocket paper, and paste it in the same manner as for the cylinders, and again a second piece over that, and notched for fixing them to the cylinders.

The cylinder-gauge is put on the rocket even with the mark that denotes the height of the clay. If the rocket does not fit the gauge tight, a slip of paper is put in to make it so; then with a knife cut off what remains of the case. The gauge is then pushed down to the $4\frac{1}{2}$ diameter mark: cut off about three or four thicknesses of the paper, and peel it off until it will fit the cylinder; then with a Reimer bore a hole through the clay, up to the surface of the composition: the cylinder is then glued on. The bursting powder is next put in: 3 drs. for a 1-℔. rocket, and 2 drs. for a $\frac{1}{2}$-℔. rocket. The stars are then placed in rows, a circle of stiff paper placed over them, and the fringe and a circle of fine paper pasted over all. The cone is then pasted on, and covered with a slip of light blue paper: it is then primed with spirits of wine and mealed powder, and is ready for service. Signal rockets for Naval Service have two coats of white paint.

Proportions of composition for making stars for signal rockets.

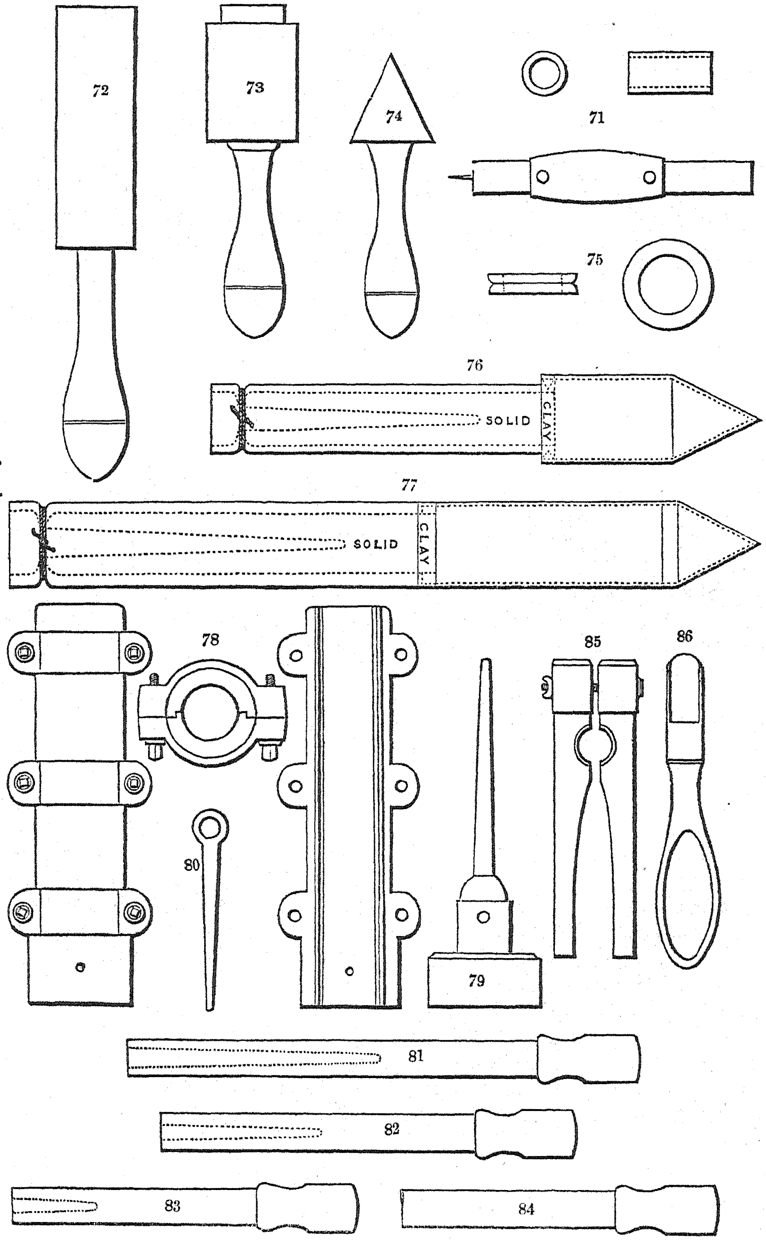
Saltpetre, pulverized	8 ℔s.
Sulphur, sublimed	2 ℔s.
Antimony, pounded	2 ℔s.
Cylinder-mealed Powder	1 ℔.
Isinglass	3 oz. 8 dr.
Vinegar	1 quart.
Spirits of Wine	1 pint.



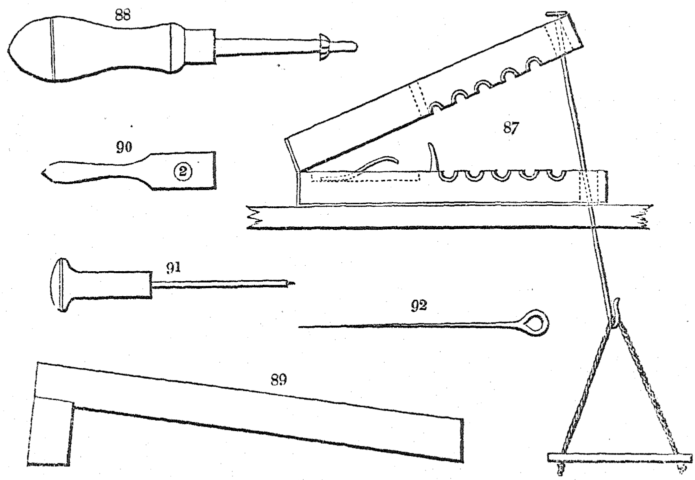
63. Diameter-gauge.
64. Slip do.
65. Choking frame.
66. Composition-gauge.
67. Pricker.
68. Setting drift.
69. Piercer.
70. Composition box.

Method of mixing the ingredients.

The antimony and saltpetre are first well mixed together with a slice, and when all of one colour, it is passed three times through a hair sieve. The isinglass and vinegar are put into a pot, and placed over a slow fire until all the isinglass has dissolved; the pot is then removed from the fire, and the spirits of wine added, and well stirred



71. Star mould.
72. Cylinder former for parallel heads.
73. Do. for projecting heads.
74. Cone former.
75. Ring—elevation—plan.
76. ½-lb. rocket complete.
77. 1-lb. do.
78. Mould.
79. Spindle.
80. Pin.
81. First hollow drift.
82. Second do.
83. Third do.
84. Solid drift.
85. Holder for drifts.
86. Ladle.



87. Spring press.
88. Slitting knife.
89. Rounding board.
90. Gauge.
91. Drift.
92. Piercer.

together with a stick. A portion of the dry composition is then put into a copper pan, and a part of the liquor also, mixing them well together till it is damp enough to adhere by the pressure of the hand. The bottom of the tray in which the stars are placed is dusted with mealed powder. A portion of the composition is then laid on a board, and placing the end of the former which has the spindle into the mould, strike it into the composition, and rub the end on the board. Turn the former in the mould, and withdraw it, and insert the longest end and displace the star. The stars are then primed with mealed powder by being turned in the tray, and the powder shook over them until all are lightly covered: they are then set aside to dry, until fit for use.

Note. — The head of a 1-℔. rocket contains 36 stars, and that of the ½-℔. rocket, 24 stars.

Tubes.

Tubes are of four different natures, viz. Common Quill and Dutch or Paper Tubes for Exercise, and Detonating Quill and Brass Tubes for Service.

Common quill tubes.

The quills are passed through a gauge 2-10ths of an inch in diameter, and are then rounded, with the back of a pair of scissors, on a board for the purpose. As much only of the point is cut off as will admit the drift without splitting the quill, which is cut to 3 inches in length. The quill is next placed in a spring press, and with a seven-bladed knife about half an inch from the large end is slit, and the prongs turned back with the fingers; then with a needle and worsted worked over and under each prong all round till it is large enough to form the cup, which is about 7-10ths of an inch in diameter.

Method of filling quill tubes.

Mealed powder is damped with spirits of wine in a copper pan, and the tube struck twice into the powder, and then rammed in hard with a brass drift. This is continued till the tube is filled, after which a brass piercer (No. 19 wire) is forced up the tube, and turned round at the same time, till a hole is made through the centre.

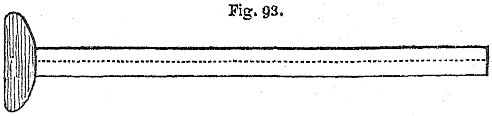
Method of priming quill tubes.

They are primed by mealed powder, damped in spirits of wine, being rubbed into the cup, which is afterwards dipped in dry mealed powder, and the tube again pierced, using No. 21 wire. They are then laid by to dry, and afterwards capped by a piece of paper being twisted over the cup.

Note.—They are packed in bundles containing 100 each.

Common quill tube.

Fig. 93.



Dutch or paper tubes.

The barrels are formed of slips of whited-brown paper, 5½ inches long and 2 inches wide. These are thinly pasted over and formed on a wire former; they are then rolled between two boards, and afterwards laid by to dry. The barrels are next dry-rubbed between the same boards, to make them round, and then cut to lengths of 1¾ inch. The tube is then put on a cupping wire, and the cup formed with a slip of paper, cut 4-10ths of an inch wide and 17 inches long. The wire is held in the left hand, and the slip between the finger and thumb of the right, and laid on a board and thinly pasted; the edge of the paper is gradually raised so as to form a cup. They are then painted twice, to make them strong before being filled.

Method of filling.

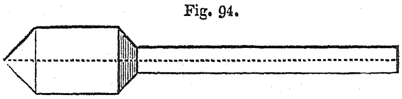
They are filled in precisely the same manner as common quill tubes.

Method of priming.

A thick paste is made of mealed powder and spirits of wine; the piercer is put through the top of the tube, about a quarter of an inch, which is then plastered so as to form a cone. Dry mealed powder is rubbed in upon it, and a cap made of fine paper put over the cup. The cap is dipped in a solution of saltpetre, and choked under the cup.

Dutch or paper tube.

Fig. 94.



Detonating or cross-headed tubes.

The quills of the detonating tubes are prepared in the first instance in the same manner as common tubes, but the small ends are not cut off, as in the latter. They are cut to 2¾ inches in length, and are without cups. A small hole is bored with a lathe through the quill, about 1-10th of an inch from the top of the large end. Small or pigeon quills are also prepared for the arms to receive the detonating composition. These are cut to ¾ of an inch in length (the small end is not cut), and a small hole is bored in the centre, to communicate the composition to the body of the tube.

Method of filling detonating tubes.

The body of the tube is filled precisely in the same way as common tubes.

The cross or arm is filled solid with the following composition, and which must be occasionally damped with spirits of wine and gum-water.

Proportions of composition for filling the crosses of detonating tubes.

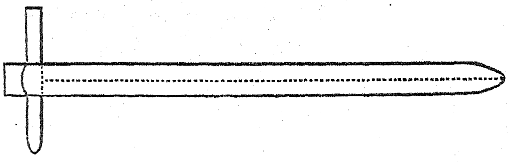
Chlorate of potassa	230 grs.
Antimony	230 „
Glass, finely pounded	73 „

The cross is then placed in the holes at the top of the body of the tube, and fastened with waxed silk. The vacancy on the top of the body is filled with fine-grain powder, and plugged up with a small portion of putty. Lastly, the head of the tube is dipped into a varnish composed of shell-lac and spirits of wine.

Note.—Great care is required in mixing the above composition, as it will sometimes ignite even in mixing with a wooden slice. The antimony and glass are first separately pounded in a mortar, and then mixed together with the chlorate, in paper, small quantities at a time.

Detonating or cross-headed tube.

Fig. 95.



Brass tubes, common.

The body is formed of the same dimensions as common quill tubes, and with a cup, also of brass, to receive the priming.

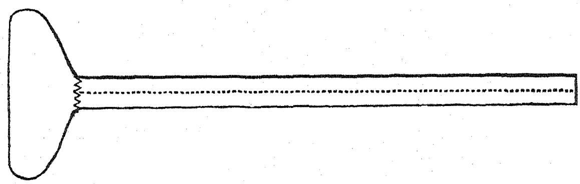
Filling brass tubes.

They are filled precisely the same as common quill tubes.

Note.—The barrel or body of every nature of tubes is of the same diameter, viz. 2-10ths of an inch.

Fig. 96.

Brass tube.



APPENDIX I.*

Of Fulminating Compositions used in Military Pyrotechnics.

There are but two distinct kinds of these compositions used in Military Pyrotechnics; one in which the fulminate of mercury is either the sole ingredient, or one which the composition contains. The other kind is that in which chlorate of potassa furnishes the detonating principle, and is combined with various combustibles; in one case, with fulminate of mercury.

Chlorate of potassa is not a combustible; its office is to furnish oxygen, a supporter of combustion, as is that of nitrate of potassa (saltpetre).

Both the nitrate and the chlorate of potassa furnish oxygen in equal volumes; but though the quantity of oxygen is the same in each, that in the chlorate of potassa, being combined with its base in feeble affinity compared with that in saltpetre, is readily disengaged by several means which will be noticed.

In the French and most other Artillery Services (our own excepted), fulminate of mercury is the chief ingredient in all military detonating compounds, to the exclusion of chlorate of potassa.

Musket caps in the British Service are primed with a composition including chlorate of potassa, with the fulminate of mercury and other sensitive combustibles, besides the fulminate of mercury.†

Cannon tubes are primed in the detonating part with a mixture of chlorate of potassa and sulphuret of antimony.

Both of these compositions may be exploded by the direct application of fire, by heat not greatly exceeding 300 degrees, by the action of concentrated nitric and sulphuric acids, by friction, and by moderate percussive force.

In preparing fulminating compounds, numerous accidents, having serious or fatal results, have happened even to scientific men and experienced manipulators: these accidents manifest that great caution is requisite to handle any of the fulminates with safety; but though perhaps it is too much to assert, that any precaution will wholly avert accidental explosions, yet a due observance of all the precautions well understood in a properly regulated Laboratory, will not only reduce them to rare occurrences, but deprive them of fatal or very serious results. However, a safe and efficient

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* By Lieut.-Colonel Stevens, Royal Marine Artillery.

† The detonating material for French musket caps is composed of two parts of the fulminate of mercury and one part of pulverized saltpetre, by weight, damped with water.—*Aide-Mémoire d'Artillerie*, p. 183.

The composition for French cannon tubes is two parts of fulminate of mercury and two of mealed powder, intimately (but carefully) mixed together, then formed into a paste by means of distilled water *slightly* impregnated with gum-arabic.—*Aide-Mémoire d'Artillerie Navale*, p. 273.

knowledge and expertness of working with the sensitive materials here spoken of, can only be acquired by instruction and practice in a Laboratory.

These fulminates, when exploded, generally fail to ignite gunpowder which may be lying near, or even touching them; the powder being blown to some distance by the force of the exploded fulminate, without being ignited.

This is usually accounted for by supposing the velocity of the flame of the fulminates is too great to permit sufficient heat to be communicated to the adjacent combustible; as an electric spark may be passed through a heap of gunpowder harmlessly, but which instantly explodes if the electric fire be arrested in its passage.

Cannon tubes and musket caps are the only cases in which fulminates are used in the British Service, except some signal portfires which are prepared for the Coast-Guard Service; these are primed with a mixture of chlorate of potassa and sugar: having placed on it a small glass bubble containing a drop of sulphuric acid, and hermetically closed, a thin paper is pasted over to keep this priming in its place; the portfire can then be lighted by breaking the glass bubble with any hard substance, when the mixture of the chlorate and sugar ignites and the portfire is lighted.

This ready and convenient mode of lighting is a temptation to extend an application of fulminates to blue lights, light balls, portfires, and many other military pyrotechnics; but the danger and uncertainty of the above compositions should peremptorily exclude this dangerous and unnecessary extension of their use.

There are other safe and convenient means by application of the common musket cap, which, being always at hand, obviates the necessity of fixing permanent percussion primings or signal lights and other military fire compositions. The musket cap may be fired in any manner that will bring it in contact with the priming of the composition, when ignited, as a tube somewhat resembling that used for firing rockets in the field, or a French *brûle amorce*, or even a circular plate of iron about 2 inches in diameter, having a nipple in the centre for the cap, which, being ignited by a blow of any hard substance, at once lights the fire-work if placed close down upon its priming; or if a few grains of powder are required to insure ignition, a musket-cartridge will always be at hand to furnish them. But these subtile agents are so sensitive, and their action so readily diverted or altogether arrested, by seemingly unimportant alterations, that it is not safe to affirm what will be the result of new applications. Little can with certainty be inferred, and each alteration should be received only when it has been abundantly tested by experiment.

In decorative and recreative fire-works, chlorate of potassa, fulminating mercury, and even more sensitive fulminates, are employed.

The brilliant purple, crimson, and green stars thrown from the heads of rockets cannot be made without either the fulminate of mercury or chlorate of potassa entering into their constituents; but these complicated though beautiful compositions are of so dangerous a nature, that no consideration should admit them into stores or magazines, or on board ships; since they are not only liable in a higher degree to the accidents pointed out, but are liable to take fire by what is termed spontaneous combustion, particularly when exposed to a hot and humid atmosphere, as several accidents from them have proved.

APPENDIX II.*

Short Notice of some Books on Military Pyrotechnics.

Casmir Siemienowitcz's Treatise, called 'the Great Art of Artillery,' was published in Latin about 1660, during the reign of 'John Casmir,' King of Poland and Sweden.

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* By Lieut.-Col. Stevens, Royal Marine Artillery.

Siemienowitcz's book was translated from a French edition in 1729: in these transits from the Latin the book has undergone evident alterations, and is interpolated with translators' remarks.

Many late improvements are there indicated, and illustrated by good engravings: amongst others, the War Rocket, very large, with metallic cases.

The mode of firing shells from long guns.

A concussion shell, though of a very rude description.

An oblong shell containing smaller missiles, and made to burst by means of a fuze, analogous to the principle of the Shrapnell-shell carcasses, light balls, &c.

It would seem that it is only owing to the advance of mechanical and chemical science, and their arts, that these inventions have been realized.

'Pyrotechnie Raisonnée,' by Moritz Meyer, published at 'Bruxelles, Société Typographique Belge, par Adolphe Wahlen et Cie,' 1827.—This book aspires to an entirely new arrangement in the manipulation of compositions for military pyrotechnics; and though all the author's ideas may not be approved, yet he furnishes valuable thoughts for simplifying the operations of a Military Laboratory.

'Nouvelles Recherches sur les Feux d'Artifice. L'auteur, 40, Rue S. Thomas-du-Louvre,' Paris, 1843. This is perhaps the best book published on decorative and recreative fireworks, containing the latest improvements, particularly those relating to coloured fires.

'Aide-Mémoire à l'Usage des Officiers d'Artillerie,' 1844, second edition.—Independent of the more scientific articles in this work, it contains an ample description of the mode of manipulation of military pyrotechnics used by the French Artillery.

'Aide-Mémoire d'Artillerie Navale,' printed by authority,—containing an account of the fabrication of percussion cannon tubes for Sea-Service guns, which is not contained in the 'Aide-Mémoire d'Artillerie.'

'Manuel d'Artificier,' or 'Manuel des Artificiers,' by Colonel Préaux.—This small pamphlet contains a very detailed account of the manufacture of percussion cannon tubes for the Navy, as practised in the French Laboratories.

Q.

QUARRY,* so called from *quadratarius*, which, in the Latin of the lower ages, was the term applied to a stonecutter, *qui marmora quadrat;* and hence *quarry*, the place where he quadrates or cuts the stones in squares. This term was originally used to signify those places where stone for building purposes was procured, but its application has been extended to all rock excavations (except mines), for whatever purpose made. Quarries are generally opened and worked for two purposes:

First, When it is immaterial what may be the shape and size of the masses of loosened rock, as in quarries for lime, road material, &c.; and excavations, such as the ditches of a fortress or cuttings of a railway, where the object may be to remove the stone, and not to save it for building purposes; and

Secondly, When the rock is obtained in blocks fitted for building purposes, in shapes easily reducible to those forms which are best adapted for the designs of the architect or sculptor.

In either case, a great object in quarrying operations, as indeed in all others, is economy, or the producing the greatest results with the available means; and for this purpose it is necessary to study closely the formation of the rock in which the excavation is to be made, in order to take advantage of those natural flaws and divisions,

* By Captain Simmons, R. E.

where they may exist, which will be found materially to lessen the labour and facilitate the operations of the quarryman. Under this head, rocks are naturally divided into stratified and unstratified. The former includes a large class of most valuable building material, such as the magnesian lime, sand and freestones, millstone grit, Yorkshire landings, &c.; many of which can be cut or forced from their original positions without the intervention of any explosive agent. The methods in use for this purpose vary in detail, but are similar in nature. They require that a surface of the rock parallel to the bed of deposit should first be laid bare, and also that the stratum or layer from which the stone is proposed to be taken should be broken through or disconnected from the general mass, so as to allow a detached portion to be removed by sliding upon its natural bed. Having marked on the exposed surface the size of the block required, its separation is effected by driving in rows of wrought-iron wedges around it. These are at moderate intervals, depending on the facility with which the rock can be cleaved, and are struck in succession until at length the openings made by them extend from one to the other, and through the stratum: the block is then free to slide from its original position. Should the stratum be too thick and firm to admit of a separation being effected in this way, a channel is sometimes cut, which may extend in some cases, in the form of the letter V, to a depth of two or even three feet, into it; and the wedges are then applied in the bottom of the channel. This, however, would only be done where the rock is of a nature which easily yields to the cutting tool (generally a pointed hammer, called a *pick-hammer*).

Occasionally also, in rocks that are easily cleaved, a row of wedges is also introduced parallel to the natural cleavage, by striking which at the same time as the others which are upon the surface, the stratum can be split so that the block procured need not extend to the full thickness of the stratum. These methods apply principally to the second case, that is, when it is desired to procure blocks fitted for building or other purposes; but it behoves the Engineer, in the event of an excavation being required in a stratified rock under the first case, viz. when the masses are not required in blocks of any particular form, to ascertain how far he may make use of this system with economy, instead of adopting the method hereafter described, when an explosive agent is used. In the case of thin strata by nature, capable of being split with facility, this system may be applied under ordinary circumstances; and when the explosive agent cannot be abundantly or readily procured, it may be carried to a greater extent.

For the purposes of quarrying under other circumstances, that is, where the rock is unstratified, or of a nature not allowing it to be readily cleaved, or where the natural divisions are so far apart as to render too laborious the application of wedges, another system is adopted, by which the rock is disrupted by explosive agencies.

Two substances, gun-cotton and powder, have been used for this object; but as the former has not as yet been brought into very general use, and cannot therefore always be procured,—more especially in the Colonies, in which are executed a large proportion of the works that are intrusted to the direction of Officers of the Royal Engineers,—and as the effects of it seem to be somewhat uncertain, depending on the manner in which it is applied and the space in which it is confined, and also, in the present state of knowledge, upon its not being very safe for general application by ordinary quarrymen,—in treating of this subject, the more generally applied and better understood explosive agent, gunpowder, will only be considered, in which much assistance has been derived from an able paper on 'Blasting Rock,' written by Major-General Sir John Burgoyne, K.C.B., and published in the fourth volume of the Professional Papers of the Corps of Royal Engineers, and also since in the form of a rudimentary treatise, by Weale, to which the reader is referred for a more extensive treatise on the subject than can be given in a work of this nature.

It is of the utmost importance to select a judicious position for the charge, with reference to the effect desired to be produced, and to the economy of the labour required to place that charge, and of the powder itself; in determining which, the following general principles will be found to apply, to which, however, sufficient attention is seldom yielded, the quarrymen being often allowed to place the charges and determine the quantities of powder according to their own notions, very often totally devoid of any definite principle.

In opening a quarry, the first object to be obtained is an exposed surface, behind which the charges being placed, they will find a less resistance than elsewhere, and will consequently force it outwards, removing the intervening matter from the principal mass. A vertical exposed surface is preferable, as being the most easy for the quarryman to place his charge behind.

Powder, when exploded, acts equally in all directions, and therefore if one part of the mass surrounding the charge be weaker, or offer less resistance than another, it must yield to a *sufficiently* powerful charge.* The distance from the centre of the charge, or of explosion, to that point on the surface at which the elastic gases produced by the explosion find the easiest access to the atmosphere, is called *the line of least resistance.* This will be the shortest when the charge is surrounded by an uniformly resisting medium; any inequality in this respect might cause a much *longer* line than that drawn directly from the charge to the surface, to be the line of least resistance, as when a mine is imperfectly tamped, or where rock and earth surround the charge. Charges of powder, when their strength is uniform, produce effects varying with their weight; that is, a double charge will move a double mass, a treble charge a treble mass, and so on; and as homogeneous masses vary as the cube of any similar line within them, the general rule is established, that charges of powder to produce similar results are to each other as the cubes of the lines of least resistance. Hence, having determined carefully by experiment the charge to produce a given effect in a particular class of substance, the charge to produce a like result on a given mass of a similar nature is readily determined.

The variety of substances acted upon, and the very great varieties in the quality of powder, render it necessary, in the undertaking of quarrying operations, that experiments should in all cases, when they are of any extent, be instituted to determine the constant which should be employed in calculating the charges of powder.

Having determined the place of the charge, it is above all things important that the line of least resistance, as decided upon, should remain that of *least* resistance, or that the aperture by which the powder is introduced should be so secured or *tamped* as not to allow an easier vent to the elastic gases formed by the explosion than this line, which has been assumed in the calculations; also that no natural flaws or fissures should be overlooked, by which the powder may find a vent. This latter means, by which the force of the explosion is sometimes lost, requires particular attention in lower geological formations, and in stratified rocks will generally determine that the line of least resistance should be perpendicular to the beds of the strata, and that the hole for the charge should be driven parallel to the strata, and so as not to touch the planes which separate them.

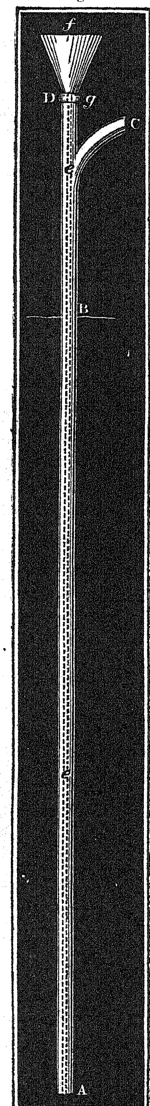
Various have been the methods tried for tamping these holes; but as none have been found practicable, which are as strong as the undisturbed rock, it is evident that the introduction of the charge in the direction of the line of least resistance

* If the mass in which the powder is placed exceed in strength its power to dislodge it, then it does not give way, but an enlargement only of the cavity in which the powder is placed occurs by the crushing to dust the parts in immediate contact with it, which receive the force of the explosion. This action is similar to that of a globe of compression.

should be avoided as much as possible, in order to save powder, as the full effect due to the powder can only then be produced by making such an increased allowance for the charge as will counterbalance the loss consequent on the diminished resistance.

Boring for Blasting.—These apertures are made by boring with iron rods called borers or jumpers, according as they are struck on their heads with a hammer or merely jumped up and down and allowed to penetrate the rock by their own weight. These are of various sizes, and have wedge-shaped pieces of steel welded to their end, called *bits*, which are brought to an edge, so as to cut into the rock. The holes may be made in almost any direction, but that which is most advantageously worked is vertical, in which case the weight of the cutting tool is brought into useful co-operation with the force employed to drive it. With the jumper it is the weight alone which produces the effect.

Fig. 1.



The speed with which holes are sunk into rock depends on the nature of the rock, and on the size and weight of the boring tools; it having been ascertained, from long experience, that three men are able to sink, in granite of good quality, at the following rates:

With a	3-inch	jumper,	4 feet	in a day.
,,	$2\frac{1}{2}$	,,	5	,,
,,	$2\frac{1}{4}$	,,	6	,,
,,	2	,,	8	,,
,,	$1\frac{3}{4}$	,,	12	,,

In working the two last classes, where the holes are not very deep, a strong boy will answer to turn the jumper. With a 1-inch jumper, a strong man bored 8 feet in a day.

In using borers, it is necessary to pay some attention to the weight of hammer used for striking them. If too heavy, by fatiguing the men and the reduced number of blows given, a less effect is produced than if lighter hammers are used; and if too light, the strength of the miner is not kept fully employed in raising the hammer. The usual weight is from 5 to 7 lbs.

It therefore is evident that it is desirable to sink the holes of as small bore as possible, considering the size of the charge, which *should in all cases* be determined by weight, and ought not to occupy too great a length in the bore-hole; the object being to get the centre of the charge as near as possible to the centre of explosion. In order to effect this object of placing a large charge at the bottom of a small hole, which is also advantageous as presenting greater facilities for tamping, various plans have been adopted. At the bottom of the bore, small charges have been placed and fired, so proportioned as not to produce fracture to the rock; they then have the effect of enlarging the space (called chamber) for another charge, which can be inserted by boring through the tamping. This operation may be repeated several times when it is desired to place a large charge at the bottom.

Another plan, applicable principally to calcareous stones, has been tried with good effect. The rock having been pierced in the usual way, a copper pipe, the size of the bore, is introduced (see fig. 1), the end A reaching to the bottom of the hole, which is closed up tight at B with clay, so that no air can escape. This pipe has a bent neck C, for a purpose hereafter to be explained.

Through the copper pipe at D a small leaden pipe is introduced, about half an inch in diameter, formed with a funnel *f* at the top, and is passed down to within about 1 inch from the bottom; the upper orifice of the copper tube round the leaden one at *g* being filled with a packing of hemp. Matters being thus adjusted, dilute nitric acid is poured through the funnel and leaden pipe, which, dissolving the calcareous rock at the bottom, causes an effervescence, and a substance containing the dissolved lime is forced out from the orifice C, the process being continued until, from the quantity of acid consumed, it is judged that the chamber is sufficiently enlarged. Other acids, such as muriatic or sulphuric, will produce the same effect, but the result of the chemical solution will depend on the nature of the stone and the proportion of its chemical constituents.

It may be assumed that 1 ℔. of powder, when loosely poured, but not shaken or compressed, will occupy about 30 cubic inches; or 1 cubic foot will weigh about $57\frac{1}{2}$ ℔s.; consequently a hole 1 inch in diameter and 1 inch in depth will weigh ·419 of an ounce, multiplying which by the square of the diameter of the hole in inches, will give the weight of an inch in depth of powder in any given hole; whence can readily be determined either the length of hole for a given charge, or the charge in a given space.

Gunpowder varies very materially in quality, a comparison between Merchants' blasting powder and Government cannon powder giving arcs by an éprouvette gun from 12·0 to 21·0 degrees: it is therefore of very great importance that powder should be tried before purchasing or commencing to use it in quarrying, so as to prevent disappointment in the expected results, or an excessive use of powder.

The benefits resulting from the use of strong powder are evident:

1st. Smaller quantities are required, and consequently less stowage room.

2ndly. Greater effect is produced in comparison to the labour expended in boring.

3rdly. Increased resistance in the tamping, the powder occupying less space, and leaving more for the tamping.

In determining the most economic method of producing a given quantity of stone from a quarry of any particular description of rock, the following points are first to be ascertained:

1. The constant from which the charge is to be calculated.
2. The speed with which holes of different bores can be driven.
3. The effect of agents, such as small charges or acids, in enlarging chambers.
4. The face which can be established in the quarry; for it is obvious that the higher this face is, if the charge is placed behind it, the greater will be the proportional effect on the mass dislodged; the powder acting on a like mass in either instance, but leaving a much greater mass to be dislodged by its own weight in the one than in the other.

These data having been determined, and the size of the block required being known, the calculation is to be made whether large charges are to be adopted or a succession of smaller ones.

Large charges have one decided advantage, not requiring that the quarry should be so often cleared of workmen during firing.

The loading of mines in rock requires great care, to prevent accidents, the safety with which the operation is performed in a great measure depending on it. A few grains of powder loose on the side of the bore-hole may produce explosion in tamping. For the purpose of loading, the use of copper vessels is recommended.

A copper canister, with cover, to contain the powder;

A set of copper measures containing given weights of powder (1 ℔., 4 oz., and 1 oz.);

A set of cylindrical tubes, 3 feet in length, $\frac{3}{4}$ inch in diameter, which can be screwed together to form a long tube, and a copper funnel.

When the charge has been placed at the bottom of the holes by means of these instruments, a Bickford's fuze, or galvanic wires in a small bursting charge, are placed upon it, and then a wadding, after which the hole is tamped, and is ready for firing.

Bickford's fuze is strongly recommended in quarrying operations at the present time. It is not expensive, is very certain in its effects, not easily damaged in tamping, and not affected by damp. In wet situations, by enclosing the charge in a canister or water-proof bag, with a fuze attached, the firing is conducted with facility.

The galvanic battery has been used in large operations with great effect: a number of charges being placed, a simultaneous effect is certain when required. This is found useful sometimes in moving large masses, and also where a number of men are working in a quarry, and they are withdrawn for the purpose of firing a mine: there is no uncertainty in their returning to their work, as immediately the wires are disconnected from the battery, there is no danger of explosion.

Tamping.—In tamping, the object desired is to obtain the greatest amount of resistance over the charge of powder. Different materials have been employed for this purpose.

The chips and dust of the quarry itself are very commonly used.

Sand poured in loose, or stirred up as it is poured in, to make it more compact.

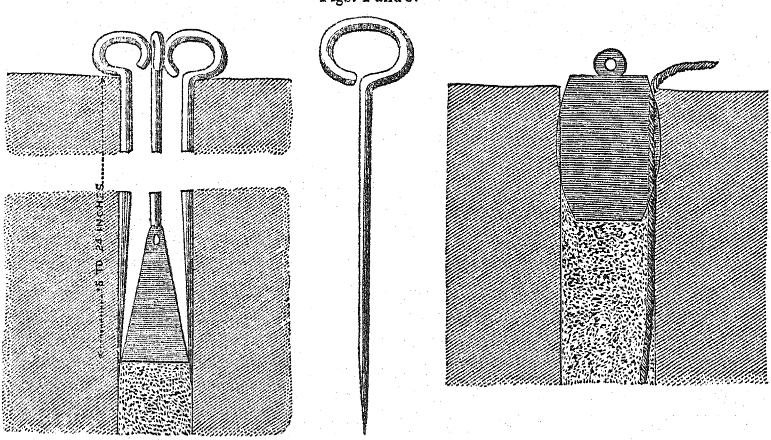
Clay, well dried, either by the sun or by fire.

Broken brick and stone.

Various opinions have been given upon these materials; and sand, as being easily used, very generally attainable, and offering a very great resistance from the friction of the particles among themselves and against the sides of the mine-hole, has been highly spoken of by French Engineers.

Experiments made by British Engineers have not given these favourable results, but have rather tended to give to well-dried clay the preference, as offering the greatest resistance.

Figs. 2 and 3.



Mechanical contrivances have also been used to assist the tamping: the sketches (figs. 2 and 3) shew what may be considered the best, consisting of an inverted cone, wedged in on the tamping with arrows, or of a barrel-shaped plug; but these would only be used in particular circumstances, when the cost and labour consequent on

their use would be well repaid by the improved effect of the explosion, such as in shafts or galleries, &c.

In rock excavations for the ditches of a fortress, or for the cutting of a railway, the economy of the operation depends in a very great degree on the skill with which powder is applied in the quarrying operations. The first thing to be obtained is a gullet or small cutting, extending throughout the work, which must be carried down rather below the bottom of the ditch or cutting. This is of great importance, and that every successive widening of the gullet should be carried down to the full depth.

In some extensive railway works, involving probably the heaviest quarrying operations in Great Britain, the cutting was carried to a depth two or three feet less than what was required of the Contractor. In taking it out, each cubic yard cost about a guinea to remove, whereas the rest of the cutting had not averaged much more than 3*s.* 6*d.* for each cubic yard.

This arose probably from neglect in the first instance, as the cutting being very deep, had the gullet been taken out to the required depth, the same quantity of powder, placed a little deeper, would have produced the effect of taking out the cutting to the required depth.

It would be wrong to conclude a subject of this nature without adverting to two of the largest explosions probably ever effected as quarrying operations; the first, in 1843, when three charges of 7500, 5500, and 5500 ℔s. were simultaneously exploded by the action of three galvanic batteries, at the Round Down Cliff, near Dover, to effect a cutting for the railway. The material acted upon was chalk, the lines of least resistance 72 and 56 feet, the charge being calculated, in pounds, as $\frac{1}{32}$nd of the cube of that line in feet, with something additional to provide against contingencies.

The mass brought down from the cliff was 400,000 cubic yards, being a parallel mass or slice from the face of the cliff, 380 feet in height, 80 feet in thickness, and 360 feet in length of face.

The other occasion was in the year 1850, when two charges of 12,000 ℔s. each were simultaneously exploded by the action of two distinct batteries, in a chalk cliff at Seaford, on the coast of Sussex, the object being to form a groin to arrest the progress of the shingle along the southern coast. The lines of least resistance in this case were 70 feet, and the charges were calculated on the same proportions as in the Round Down explosion, and placed 120 feet apart. The operation was most successful, the mass brought down being 211 feet in height (the whole height of the cliff), about 240 on the face, by a depth of about 90 feet.

In both of these cases the force of the powder acted to blow out a crater, (the lines of least resistance being horizontal,) which bore but a small proportion to the mass dislodged. This mass was brought down principally by its own weight, having been deprived of support by the removal of the substance within the crater.

These explosions tend to establish entire confidence in the proportion of charge adopted for the material (chalk) in which they took place.

It is probable that a slight increase might be required in some descriptions of rock, but the chalk operated upon being of a very firm and homogeneous nature, and very free from fissures, would lead to the conclusion that no material would require a much greater proportion of charge.

QUARTERING OF TROOPS.*—My attention having been again called to this subject, I propose to offer some observations with reference to my Report to the Inspector-General of Fortifications, dated 3rd March, 1847.

* By Colonel Thomson, R.E.

1. The subject naturally divides itself into a consideration of the best proportions of barrack rooms, and on the mode of heating, lighting, and ventilating them, &c.

2. With respect to the proportion of barrack rooms, the bed being 2′ 4″ in breadth, I propose to increase the space between the beds to two feet, and between the end beds and the wall to one foot. It must not be supposed that this will increase the cost of barrack buildings, for that is already determined by the Master-General and Board's Order of 17th April, 1845, fixing the number of cubic feet per man at 500.

It may here be questioned whether the extent of space is sufficient, inasmuch as the Board of Health state that 700 cubic feet of air are necessary to support life per man, and the Inspectors of Prisons allow 1000 cubic feet for each prisoner.

On entering a barrack at night which is fully occupied, and has been closed for some hours, the impure state of the air is fully proved by the intolerable smell, more especially if no attempt has been made at ventilation. In the process of transpiration, vapour is continually given off, which, together with the vapour expelled from the lungs, amounts to two fluid ounces per man per hour. Thus, supposing the night to last eight hours, and the room to contain twelve men, the vapour given off will amount to 192 fluid ounces during the night, or 16 ℔s. of water, which, if not carried away, saturates everything in the room, after it has been breathed over and over again, in conjunction with the impurities it contains, collected from each individual. This system of forcing men to breathe a vitiated air for so long a time must have the effect of filling the Hospitals. The length of the room will thus be determined according to the number of men to be accommodated.

3. The breadth of the room should be such that a bed may stand conveniently between the projection of the chimney and the side walls. With this view I propose 22 feet as a fixed number for the breadth.

4. In order to carry out the circular before quoted, the height of the room should be 10 feet 6 inches, which will give 500 cubic feet of space per man.

5. If the interval between the beds were reduced to 10 inches, and the breadth of the room to 20 feet (as formerly), the height must be increased to 15 feet, which would render 30 steps necessary in the staircase between the stories, whereas 21 steps would be sufficient for the arrangement proposed. The wear and tear of steps in barracks is very great, and their repair is extremely inconvenient in occupied buildings. It is therefore very desirable to reduce the number of steps as far as may be practicable, and in all cases to construct the treads of 2-inch oak.

6. *On Heating Barrack Rooms.*—The grates now in use are very objectionable in many respects; they are heavy, and the grating is too far removed from the level of the hearth. Being all of the same size, they afford the same heat, whether the room be small or large. Having square cheeks, they prevent to a great extent the radiation of heat. The sides and back are made of iron, which, being a quick conductor of heat, is improperly applied. The shape and construction is such as to favour the smoking of the chimney, to the great discomfort of the soldier. In the communication to which I referred at the commencement of this article, I submitted drawings of a grate for a barrack room. The object I had in view was to obviate the inconveniences adverted to,—to give the back and sides of a slow or non-conducting substance (fire-stone or fire-brick),—to give every facility to the radiation of heat,—to contract the opening into the flue to such an area as would prevent smoke, and give a facility for increasing this opening, by means of a joint, when the flue requires to be swept; and lastly, to furnish a cheerful appearance and comfort in the barrack room.

7. The proportion which I would recommend between the grate and the room to be warmed by it is one inch of front bar to each foot of the mean between the length

and breadth of the room. Thus a room $39' \times 22'$, giving a mean of 30 feet, will require an opening of chimney of 4′ 4″ horizontal by 3′ 3″ perpendicular, the latter dimension being constant for all sizes of rooms. The flue of the chimney in the brickwork should in this case be $9'' \times 13\frac{1}{2}''$, giving an area of 121 inches; but the pot on the top, where the smoke issues into the open air, should be regulated by the rule laid down by Tredgold, viz. "Let 17 times the length of the grate in inches be divided by the square root of the height of the chimney in feet, and the quotient is the area of the aperture at the top of the chimney, in inches." In this case the length of the grate is 30 inches, and supposing the total height at 25 feet, then the statement is $\frac{30 \times 17}{5} = 102$ inches area, or a clay pot of $11\frac{3}{8}$ inches diameter, or a slate top of 10 inches square.

8. The size of the rooms, according to the premises here laid down, will be as follows:

18 men,	39′	×	22′	×	10′ 6″
16 ,,	34·8′	×	do.	×	do.
14 ,,	30·4′	×	do.	×	do.
12 ,,	26′	×	do.	×	do.

A room for 18 men is the maximum size which should be introduced into barrack buildings, because it is the largest room which can be heated by one fire-place.

9. I will now proceed to consider the subject of *Light*. In order to obtain a due proportion of window-light, the rule is to find the cubic contents of the room in feet, and to extract the square root, which will give the area in feet of the window or windows required. Divide this into as many parts as the room will admit of windows. For example, suppose a room for 18 men of the dimensions already stated. The cubic contents are 9000 feet, the square root of which is 95 feet, to be divided into four windows of 24 feet area each. For the width of windows, Sir William Chambers has observed that he generally added the depth and height of the rooms on the principal floors together, and took $\frac{1}{8}$th of the sum for the width of the window. Thus, to find the width of window for a room whose dimensions have been stated, the case will be $\frac{22 + 10 \cdot 6}{8} = 4$ feet, the width required. The dimensions of the windows will therefore be $4' \times 6' = 24$ feet area each. The top of the window should not be higher than 1 foot 6 inches from the ceiling line. The pier between the windows should never be less than the width of the window, otherwise it has a weak and diminutive effect.

10. There are serious objections to enlarging the apertures of the windows beyond what the rule prescribes; for the cost of the building is increased, the air in the rooms is cooled proportionally in winter, and the expenditure of fuel must be augmented, in order to maintain a given temperature. Independently of the inconvenience arising from a glare of light (especially where the rooms face the south or west), during summer the rooms are over-heated.

11. The principle of ventilation is to admit pure air and to give an outlet for the vitiated air; the pure air to be admitted at the door within four or five feet of the floor level, and the vitiated air to escape by an opening or openings at the ceiling. The rule laid down by Tredgold for the area of the tubes for the exit of foul air is as follows: "Multiply the number of people the room is to contain by 4, and divide by 43 times the square root of the height of the tubes, in feet, (measured from the floor-line to the exit into the external air,) and the quotient is the area of the tube or tubes, in feet." Three-quarters of the area, as found by the above rule, is sufficient

for the inlet of pure air, as the air is not yet expanded by heat. The inlet flues may be made in the panels of the door, in the manner of Venetian blinds, so that the quantity of air admitted may be regulated. The exit flues may be let into the ceiling, and made of zinc, in the form of a cone of 5 or 6 inches at the large end, and $1\frac{1}{2}$ inch at the small end. The larger diameter of the cone or cones to be flush with the ceiling, and the tube to be carried outwards through the external wall, having a fall of about 1 inch in 10 feet, in order to facilitate the outward current; for the heated air will, on ascending, be condensed within the tube, on meeting the cold air, in the form of water, and a means of escape will thus be afforded.

12. Barrack rooms should consist of two floors, that is, a ground-floor and a one-pair floor. If carried higher, they are rendered very inconvenient.

13. The practice of allowing married people to live in the same rooms with the single men, having no greater separation between them than what may be afforded perhaps by an old sheet hung over a piece of twine stretched across the room, is extremely objectionable, and subversive of the *Morale* of the Army. It is, in fact, a national disgrace, and ought to be entirely prevented. The married people might be allowed lodging money, or, what is better, cottages might be erected within the barrack boundaries, designed expressly for the married people, in which each married couple should be allowed one small room.

The privies allowed to the men are extremely objectionable and disgusting. I conceive that each space or division should be 6′ 2″ by 3′ 8″, properly fitted up with one seat, and to be occupied by one person at a time. Each space to be divided by a 2-inch framed partition, having panels bead and flush, and 6 feet high, and to be entered by an external door. I propose to construct these privies in such a manner that they may have partly the advantage of water-closets, and prevent any back current of foul air.

Any plan which favours the accumulation of vitiated air must undoubtedly be unwholesome, and therefore the old cesspool system must be highly objectionable, having a tendency to disease and death.

Officers ought certainly to be allowed water-closets. I conceive that two water-closets ought to be placed at the end of each passage in Officers' barracks, and built on the very best construction.

In the construction of the floors, it would be highly advantageous to render them fire-proof.—R. T.

Dover, Nov. 12, 1850.

R.

RAILWAY.*

Preliminary Remarks.—Facility of intercourse between different districts is so essential to the development of the prosperity of countries and to the general advancement of civilization, that the introduction of railways will ever be looked upon as a remarkable epoch in the history of the world.

The immense benefits arising from the increased rapidity and ease of communication afforded by railways caused their speedy adoption on the Continent of Europe as well as in the United States; but they originated in England; and therefore the experience which is always required to perfect a new system has been chiefly acquired in this country, and has increased the cost of our own railways for the benefit of our neighbours. Hence, whilst the works of continental railways are constructed on principles quite as durable as ours, they have been executed at a less comparative cost.

* By Lieut. Douglas Galton, R.E.

In America, however, where the feeling appears to prevail of constructing only for the present, railway works have been executed with less regard to durability and much less expensively than our own. In projecting a railway for one of our Colonies, the mode of construction to be adopted should be derived from a careful consideration of the advantages and disadvantages attendant upon each system with reference to the special circumstances of the case;—the probability also that in an imperfectly known and partly explored country, future discoveries, and the determination of the sites of towns and villages dependent on them, may require deviations in the course of a railway, should also be considered with reference to the permanency and nature of the works: it is therefore here proposed, after sketching the general principles applicable to railways in this country, to append a few remarks on the American mode of construction.

The plan of facilitating the draught of carriages by forming a hard continuous surface for the wheels to run upon is old and simple; and the successive adaptations of flagstones, pieces of wood, and iron rails to the purpose, are the several improvements it has undergone.

As early as in 1649, a wooden railway for coal was in use near Newcastle-upon-Tyne, on which one horse could draw four or five chaldrons. The frequent repairs which this mode of construction required led Mr. Reynolds, of Coalbrook Dale, to substitute, in 1767, plates of cast iron; these were nailed to longitudinal sleepers, and a flange was affixed to each plate to keep the carriage in place. In this form they were known as tram-plates; and tramways, on which the plates were attached either to stone blocks or to transverse or longitudinal sleepers, were extensively used in the mineral districts of this country. This arrangement, however, which was defective because it permitted the accumulation of dirt, was at length superseded, in 1789, by an edge-rail, the flange being transferred to the wheel. Stone bearers for the rails came into use in 1800; and in 1820 Mr. Birkenshaw obtained a patent for making the rails of wrought iron.

Until 1825, railways had been almost exclusively constructed for the transport of coal, ores, slate, &c.; but in that year a company was incorporated by Act of Parliament for the purpose of making a railway from Stockton to Darlington, to convey passengers as well as goods. The Liverpool and Manchester Railway Company was incorporated in 1826, and the London and Birmingham Company in 1833, although projected some years previously. These railways, when first talked of, were intended to have been worked by horses; and so little was the present amount of traffic foreseen, that the latter railway was originally projected for one line of rails. The rapid increase of railways since 1826 has been owing to the successful substitution of steam for horse-power, and to the great improvements which have taken, and are still taking, place in the Locomotive Engine.

As far back as in 1802, Richard Trevithick took out the first patent for adapting a steam engine to move along a road, although Watt is said to have invented one previously: in 1811, Mr. Blenkinsop patented the first double-cylindered engine; it weighed 5 tons, and could draw 4 tons on a level at 3½ miles per hour. In 1829, the Liverpool and Manchester Railway Company offered a premium of £500 for the best locomotive engine. The prize was adjudged to the 'Rocket,' designed by Mr. Robert Stephenson, weighing 7½ tons, and able to draw 44 tons' load at 14 miles per hour on a level. The principal improvement in speed was due to the increase of evaporating power obtained by the use of a tubular boiler. In 1838, the principle of working locomotives expansively came into use; and this, together with alterations in the valves, &c., diminished the consumption of fuel by between one-quarter and one-half.

Since that period, the improvements in railways and engines have been so rapid, that it would be beyond the limits of this article to follow them.

Gauges. — The gauge of the lines at first constructed was the same as that of the tramways near Darlington, viz. 4 feet $8\frac{1}{2}$ inches. The Great Western Railway Company, incorporated in 1835, adopted a gauge of 7 feet. The promoters of this increased width of gauge expected to obtain by it greater convenience and stability in the carriages, a less amount of friction, and a more roomy and therefore more powerful description of engine; whilst its opponents considered it would involve an increased expense in constructing and maintaining the permanent way, which would not be counterbalanced by the advantages to be derived from it. A Commission was appointed by Government, in 1845, to inquire into and report upon the merits of the respective gauges; and a Report upon the same subject was made, in 1848, by the Commissioners of Railways, to an order of the House of Lords. From these Reports it appears that there is not any material difference in the relative advantages of the two gauges so far as goods traffic, or traffic at low velocities, is concerned; but that the largest engines on the broad-gauge lines can draw an ordinary passenger train of 60 tons with as much facility on a level, at 60 miles per hour, as the narrow-gauge engines can at 50,—that on descending gradients they retain the advantage until considerations of safety limit the speed,—and that on ascending gradients the superiority of the broad gauge, after a certain point, will diminish as the gradients increase in steepness. The railways for which Acts were obtained after this variation of gauge had been projected, adopted the gauge of the line with which they communicated, and the break of gauge which has thus been permitted is a serious inconvenience, both in a commercial and a military point of view.

It is probable that if railways had to be laid down again in England, the experience which has been acquired would cause the adoption of an intermediate gauge. This has been the case in Ireland, where the gauge has been made 5 feet 3 inches wide, on the assumption that it would allow sufficient width for the requirements of the engine without materially increasing the expenses of construction. In those Colonies, therefore, where a new system of railways has to be laid down, which can never be connected with lines already in existence, it is possible that this latter gauge might be found most advantageous.

Competing Lines. — The private Companies who first undertook to construct railways intended them to be public means of conveyance, like canals and turnpike-roads, on which any one might conduct trains of passengers or goods on paying a regulated toll; as, however, the high velocities attained required, with a view to safety, a punctual adherence to fixed hours of arrival and departure, and an implicit obedience to signals and other regulations for the safety of the traffic, it was found absolutely necessary that the general working of a line should be under the control of one head; and hence the present system has grown up of Railway Companies being carriers on as well as possessors of the various lines, by which means they have completely monopolized the main traffic of the country; and as long as this system obtains, there is no way of preventing it, as it is only in districts possessing an extraordinary amount of population or of traffic that parallel lines of railway could pay; and even where they could pay, competing lines would soon come to an agreement, the great outlay of capital securing them from further competition; and it might probably be more advantageous for the work to be done by one Company, provided that, were the amount so great as to cause obstruction or danger, the Company should lay down additional lines of rails. Since, therefore, the comfort of the Public is so much at the mercy of Railway Companies,— that the capital invested in railways is so large in amount as to exercise an impor-

tant influence on the money-market of the country, — and that the powers which Companies obtain from Parliament are so extensive, — it has become a subject of considerable discussion how far the Government should interfere in the management, or examine the accounts, of Railway Companies. The duties of Engineer Officers in the Colonies may so frequently call upon them to consider the question of railways in a political as well as in an economical and engineering point of view, that no apology appears to be necessary for endeavouring to direct attention to the subject by the above remarks.

Legislative Enactments. — The only General Acts of consequence which have hitherto been passed concerning railways were to regulate the conveyance of mails and of troops; and one in 1845 to render all subsequent lines liable to a revision of tolls after ten years, if their dividends for the preceding three years should equal or exceed ten per cent. per annum; to compel Companies to run one train each way daily, of carriages and at times approved of by the Government, at a speed of not less than 12 miles per hour including stoppages, and at fares not exceeding 1*d.* per mile. The right of purchasing any railway at the expiration of 21 years from the passing of the Act, on repayment of the capital, is also reserved to the Government. By the terms of the Act for the conveyance of troops, Railway Companies are bound to convey Officers, with 1 cwt. of personal baggage each, in first-class carriages, at 2*d.* per mile; and soldiers, with $\frac{1}{2}$ cwt. of baggage, in second-class carriages, at 1*d.* per mile; and their families at similar rates. Extra baggage is liable to be charged $\frac{1}{2}$*d.* per lb.; and military stores, exclusive of gunpowder, 2*d.* per ton per mile.

Objects and Advantages of Railways. — Railways may be projected either for commercial, political, or military purposes; and the judicious selection of a line will depend as much upon the merits it possesses in an engineering point of view, and the collateral advantages it embraces, as upon its fulfilling the main objects of its promoters.

A railway, except when it is intended to fulfil some political or military object, is a matter of mercantile consideration; and the expense at which it can be worked must therefore effect such a saving upon the cost of the existing means of conveyance as to afford a fair remuneration on the capital expended. When, however, a railway is once made, the advantages which the travelling public acquire from it are to a certain extent independent of the cost of construction or of working, as it is the interest of a Company to charge that fare which is expected to produce a maximum net profit; and this will increase with the facilities afforded for travelling, and, to a certain point, with the diminution of price. But, besides the advantages of cheapness and speed in travelling which the public derive from railways, they also profit by the increased rapidity and certainty in the conveyance of goods, which enables dealers residing at a distance from the main points of supply to procure the articles they require at so short a notice as not to be obliged to keep large stocks on hand; and this again releases, for other uses, capital so tied up.

The advantage of a railway to its proprietors is measured practically by the profits it yields to them; and these depend upon the original cost of construction, upon the expense of maintaining and of working the line, and upon the amount of traffic.

The capital which is expended upon the construction of a railway varies with the quantity and value of the land, the quality of the soil, the nature and geological structure of the country (which determines the amount of engineering works), and the price of labour.—The expense of working and of maintaining a line is regulated by the severity of the gradients and the cost of fuel and of labour.—And the amount of traffic depends on the number, occupations, and habits of the inhabitants of the towns and districts through which the line passes, on their productions and requirements, and on the markets which the railway may render available to them. And since the profit to be derived from a railway depends upon the excess of the receipts

from traffic over the expenses of working and maintenance, it is necessary that the line should be laid out not only with a view to the greatest economy in the cost of construction, but to possess facilities in working, to pass near towns and through populous districts, and to be of easy access.

In the following remarks it is endeavoured to shew the principal points connected—

1st, With construction,

2ndly, With working,

3rdly, With the amount of traffic to be expected upon, a railway.

Construction of Railways.—Cost.—The original cost of constructing railways in this country may be classed under six heads, viz. Law and Parliamentary Expenses, Engineering, Land and Compensation, Works, Locomotive and Carrying Stock, Interest and Miscellaneous.

An average taken from above fifty railways gives the total cost per mile at £34,000; but as these railways were among the earliest made, and as a diminution of expense has since taken place under some of the heads, it is probable that the present average will be considerably lower: it may, however, be assumed that the per-centage of each of the above-mentioned heads, upon the total cost of construction, is for

Law and Parliamentary Expenses	2·75
Engineering	1·75
Land and Compensation	15·00
Works	70·00
Working Stock	7·50
Interest and Miscellaneous	3·00
	100·00

The cost per mile of some few railways, selected from different parts of the country, may be interesting, when classed under the principal heads.

Name of Railway.	Land and Compensation.	Works.	Rails.	Total cost per mile.
	£.	£.	£.	£.
London and Birmingham	7,700	36,900	4,400	53,700
Great Western	6,400	32,500	9,400	56,200
Birmingham and Gloucester	3,200	14,500	3,300	24,700
London and Brighton	8,800	39,300	3,600	61,000
London and Blackwall	113,500	98,500	4,000	253,000
Leicester and Swannington	1,000	5,700	700	8,700

The amount required, in this country, for parliamentary expenses is comparatively large; and this is due to the system which has been adopted for the settlement of questions of this nature by the Houses of Parliament, who refer the consideration of the relative merits of the proposed lines to Committees of their own Members, instead of laying down rules for the guidance of some separate competent tribunal. Formerly there was no means of securing uniformity in the powers conferred by the Special Acts; but in 1845 the Consolidation Acts were passed, by which all the clauses relating to taking land, raising capital, &c., were collected into two Acts (the Railway and Lands Clauses Consolidation Acts), which are now incorporated with every Special Act, and from which no deviation is permitted without good cause being shewn.

Survey.—The preliminary survey required to enable Committees of the Houses of Parliament to judge of the merits of projected lines must be sufficient for the plans to shew the direction of the line, the various properties severed or affected, as well as those of which portions would require to be taken, and it extends usually to 100 yards on each side of the proposed line. A section corresponding to the upper surface of the rails is also made, on which is marked the level of the railway

with respect to the surface of every turnpike-road, public carriage-road, river, canal, or railway, with the heights and spans of bridges and viaducts.

It is convenient, in the sections, to make the horizontal and vertical scale of the same denomination, the one being in chains and the other in feet: 25 to 1 inch will be found to be a good one. The plan shewing the general direction of the line is generally on a scale of 1 inch to a mile,—the plan for defining the properties on a scale of 6 inches to a mile.

The cost will probably average £50 per mile in this country. The expense of the special survey made after the Act has been obtained, including setting out the line, may be assumed at from £90 to £100 per mile.

Curves and Gradients.—A railway approaches perfection in so far as it approximates to a horizontal straight line; but questions of economy, arising from the intervention of natural and artificial obstructions, or the advantage of passing through particular districts, induce deviations in practice; and the consequent introduction of curves and gradients should be limited by considering at what point the increase in the working expenses caused by them will equal the interest on the capital saved in the construction of the line. Before proceeding further, therefore, it will be desirable to make a few remarks on the mechanical effects of curves and gradients.

Curves.—When a railway carriage moves on a curve, the resistance it meets with is due partly to the effect of centrifugal force, which causes the flange of the outer wheel to press against the rail; partly to the dragging of the wheels, which, being fixed to the axles (on account of its having been found nearly impossible to make them run true when moveable), are obliged to perform an equal number of revolutions, whether on the inner or outer rail; and partly to the axles being parallel. These causes, combined, produce great wear and tear, the exact amount of which, however, cannot be easily ascertained. The centrifugal force can be counteracted by raising the outer rail above the level of the inner one, just so much as would form the roadway into an inclined plane on which the tendency of the carriage to slide towards the centre of the curve by its own gravity, would exactly balance the tendency to leave the rails. The precise mode of estimating the elevation of the outer rail will be stated in describing the permanent way.

The resistance arising from the dragging caused by the wheels being fixed to the axles is diminished by the wheels being coned: the inclination usually adopted is from about $\frac{1}{7}$th to $\frac{1}{12}$th.

Curves having a radius of 60 chains do not materially affect the rate of speed.

Curves with a radius of less than 40 chains are considered sharp.

On the Great Western Railway, the curves are chiefly of 4, 5, and 6 miles radius. On the Bristol and Gloucester, and Edinburgh and Glasgow Railways, the average radius is 1 mile, and on the Manchester and Leeds Railway 60 chains. Small radii may be used at or near termini or junctions, &c., which are arrived at or departed from at diminished speeds.

Gradients.—The term gradient has been adopted to indicate those slight inclinations up which a load may be taken, although with diminished velocity, without assisting power, being thus distinguished from those steeper slopes termed inclined planes, where assisting power is intended to be used. The relative capacity of lines for traffic is theoretically limited by their gradients, and this will be the practical limit for goods trains on lines where the traffic is heavy; but where the traffic is so small that the engines are not obliged to exert their full power on the level, as usually is the case with passenger trains, the increased charge which steep gradients would occasion in the working expenses is of comparatively less importance. The question of the economy of making gradients depends upon whether the interest

upon the capital saved by their introduction will be greater than the increased charge they will bring on the working expenses. Whilst, however, it is true that for goods traffic the effect of gradients will be to limit the load, except in cases where assistant engines are kept, and, consequently, to increase the cost of locomotive power, it must be remembered, that the disadvantage of the ascending gradient is in some degree counterbalanced by the benefit derived from the descending gradient.

The following Table has been constructed for the purpose of giving an idea of the relative advantages which different gradients would afford for goods traffic; the dimensions of the engine being assumed as follows: cylinder 16 inches diameter—length of stroke 24 inches—diameter of wheels 5 feet—weight of engine and tender 32 tons—adhesion 4480 lbs.—wheels coupled.

Inclination.	Load in tons, with which the engine can maintain a speed of 10 miles per hour.		Estimated cost per ton per mile of net load.			Remarks.
	Gross load in tons.	Net load in tons, exclusive of carriages.	Locomotive power.	Carriages.	Terminal charges.	
Level	500	312	·035 *d*	The cost for the deterioration of carriages may be assumed at ¼*d*. per carriage per mile, or about ·062*d*. per ton per mile.	These charges are to a great extent independent of the amount of goods conveyed, but may be assumed probably at 1*s*. per ton per mile.	The charges in this Table are not intended to include the maintenance of way, or the salaries of officers, &c., as it is only intended to give some idea of the relative effect upon goods traffic caused by different gradients.
1 in 5000	482	300	·036			
1 in 1000	398	224	·049			
1 in 500	317	190	·057			
1 in 250	249	145	·075			
1 in 200	222	127	·086			
1 in 150	187	104	·105			
1 in 100	142	73	·150			
1 in 90	132	66	·166			
1 in 80	121	59	·186			
1 in 70	105	50	·220			
1 in 60	96	43	·225			
1 in 50	83	34	·323			
1 in 40	69	24	·458			
1 in 30	53	14	·785			
1 in 20	37	3	3·666			

With passenger traffic, when the trains are comparatively light, the effect of gradients would be to diminish the speed; and the accompanying Table has been prepared for the purpose of shewing the comparative effects of different degrees of inclination.

Gradient.	Velocity in miles per hour.	Multiplier for distance in yards to give time in seconds.	Remarks.
Level.	54	·0375	
1 in 2500	52	·0393	
1 in 1000	50·84	·0402	
1 in 750	50·06	·0409	
1 in 500	49·26	·0416	
1 in 250	46·65	·0438	
1 in 150	43·15	·0474	
1 in 120	41·31	·0495	
1 in 100	39·81	·0514	
1 in 90	39·18	·0522	
1 in 80	32·80	·0624	
1 in 70	23·60	·0856	
1 in 60	10	·2045	

The values in the preceding Table depend almost entirely upon quantities which are continually varying; hence the mode adopted has been to assume such as are most probable for the present day; and since in comparing the values of different gradients the differences alone will be looked to, the errors will be of less importance.

The following are the assumed dimensions of the engine, from which the Table has been calculated: diameter of cylinders 16 inches—length of stroke 21 inches—steam cut off at $\frac{5}{8}$ths of the stroke—diameter of driving-wheel 6 feet 6 inches—weight of engine and tender 32 tons—adhesion 3700 ℔s.—evaporating power 200 cubic feet per hour—elasticity of steam in the boiler 95 ℔s. per square inch—pressure 80 ℔s. per square inch—load 50 tons, exclusive of engine and tender.

All gradients above 1 in 330 are considered first-class gradients. From 1 in 330 to 1 in 150 are fair working gradients.

The gradients on the London and Birmingham and Trent Valley lines are not steeper than 1 in 330; on the Dalkeith Branch of the North British Railway there is a gradient 8 miles long at 1 in 70; on the South Devon line (broad-gauge) there is a gradient of 1 in 43, $2\frac{1}{2}$ miles long; and the Lickey incline on the Birmingham and Gloucester Railway is 2 miles long, at 1 in $37\frac{1}{2}$.

Laying out a Railway.—It is usual in laying out a railway to mark a centre line by stumps, for the levels, placed at intervals of 1 chain, and a spitlock for the direction, on each side of which the width required for the roadway and slopes of the cuttings and embankments is laid off: posts are also fixed in secure positions at every 10 chains along the line, as well as at the crossings of roads and the ends of viaducts and tunnels, as references for the levels. In laying out curves on railways, numerous methods will readily suggest themselves, according to the circumstances in each case; as, for instance, by measuring offsets from the tangents and chords of the arcs, or by the intersections of angles from two theodolites, one placed at each extremity of the curve, &c., &c.

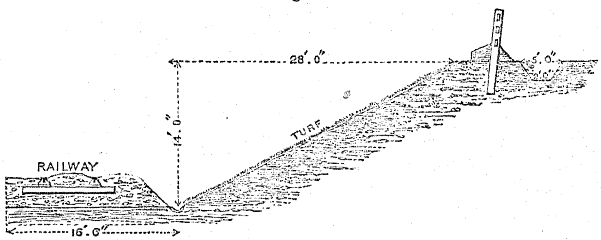
Quantity of Land necessary.—The quantity of land required for a double line of railway will vary with the nature of the country: the actual width of the railway, including fences, is about a chain, or 8 acres per mile, and when the space for the slopes of embankments and cuttings has been added, it may be considered that the average quantity per mile is not less than 10 acres in very level country, 12 acres in ordinary country, and from 15 to 20 acres in very unequal country; and 1 acre per mile additional should be allowed for stations.

Earthworks.—The amount of earthwork, of course, depends upon the nature of the country; but an average taken from twelve railways gives 104,900 cubic yards of excavation per mile, which may not be considered a very exorbitant amount; the excavation on the London and Brighton Railway being 156,000, and that on the Birmingham and Gloucester 79,000, cubic feet per mile.

To avoid a useless expenditure of labour, the amount of cutting should be proportioned to that of embankment; but when the quantity required in the embankment cannot be equalized with that obtained from the cutting, a convenient spot is selected for depositing the surplus, or excavating for the supply of the deficiency. When the earth from the excavation is in excess of that required for the embankment, it would perhaps in many cases be found advantageous to use the surplus in widening adjacent embankments. It is generally considered cheaper to throw to spoil than to lead three miles, though this would of course depend partly upon the height of the embankment for which side-cuttings would have to be resorted to, and partly on the facility of obtaining a site for depositing the surplus. In estimating the relative quantities, regard should be had to the nature of the soil.

Before commencing any cutting or embankment, all turf and surface soil should be carefully removed, and saved for soiling the slopes. In cuttings, the accumulation of water should be guarded against by inclining the bed of the excavation, and providing drains amply sufficient for the largest amount of water that could possibly be required to be discharged from the cutting; and all soft material in the cutting should be thrown to spoil. In some soils it may be necessary to discontinue the formation of embankments during inclement weather, as some soils will stand when deposited dry, which, if deposited wet, will always be liable to slip.

Fig. 1.

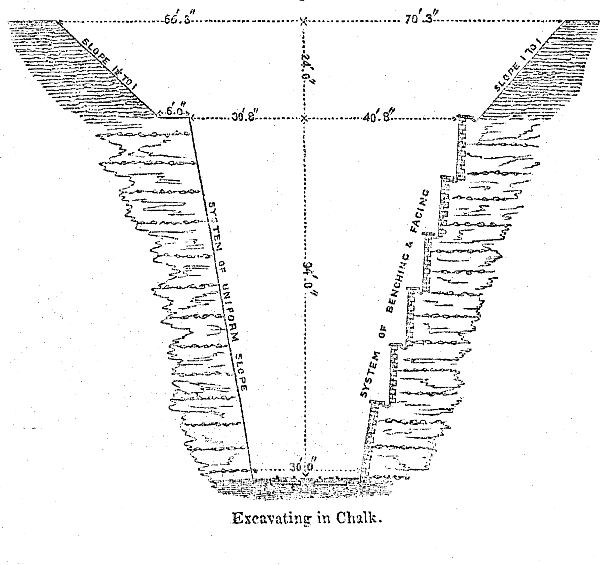


Section of Cutting.

The slopes of the cuttings and embankments depend on the nature of the soil, which should be carefully ascertained by boring. In all stratified rocks, the direction and amount of the dip of the strata become important considerations in determining the form to be given to the sides of the cuttings. Other rock stands nearly vertical. Slaty rock disintegrates when exposed to frost, but suffers less from the weather as it approaches the perpendicular, and therefore it is advisable to form the slope into steps, and cover it with vegetable mould.

Chalk varies from $\frac{1}{6}$ to 1 to 1 to 1; it frequently falls in large masses after frost or rain: layers of flint interspersed assist in maintaining the slope. In some chalks, the lower beds disintegrate much sooner than the upper one; and to obviate the inconveniences arising from this, a system of benching and facing with brickwork has been proposed, as shewn in the accompanying wood-cut.

Fig. 2.



Excavating in Chalk.

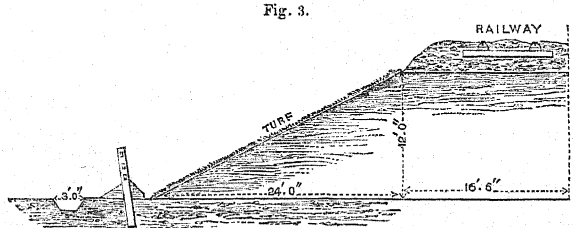
Coal measures stand at $1\frac{1}{2}$ to 1. Lias stands at $1\frac{1}{2}$ to 1, or 1 to 1, according as clay or limestone predominates. Clay is of so treacherous a nature that no average slope can be given for it: its trustworthiness depends on its constituent parts, and the drainage must be most carefully attended to: it has been known to vary from 1 to 1 to 10 to 1. Sand has stood at 1 to 1. On the Newcastle and Carlisle Railway there is a cutting through sand 100 feet deep, which stands at $1\frac{1}{2}$ to 1, Marl will stand at from $1\frac{1}{4}$ to 1 to 1 to 1;—gravel and dry soils, $1\frac{1}{2}$ to 1; or when the depth does not exceed 10 or 15 feet, 1 to 1;—dry hard shale, 1 to 1. Soapy shale will slip at a greater slope than 5 to 1.

The following Table shews the angles, obtained by experiment, at which several earths stand:

Description of Earth.	Angle at which it will stand.	Name of Observer.
Earth, common, pulverized and dry	46° 50′	M. Rondelet.
Do. common, damp	54°	Do.
Do. dense and compact	55°	Professor Barlow.
Flint, large	40° to 45°	Mr. G. Rennie.
Do. half the size of the above . .	35°	Do.
Do. approaching sand	34° to 35°	Do.
Gravel	37°	Lieut. Hope, R. E.
Do. common	35° to 36°	Mr. G. Rennie.
Do. coarse	35° to 38°	Do.
Do. Thames, wet, ...	35° to 36°	Do.
Mould, common	37°	Do.
Quicksand, Thames, dry	35°	Do.
Sand, fine, dry	35° 30′	Professor Barlow, M. Rondelet, and Lieut. Hope, R. E.
Do. dry	40°	Mr. G. Rennie.
Do. less dry	39° 9′	Do.
Shingle, loose, dry	39°	Major-Gen. Sir Charles Pasley, K. C. B.

In excavations, strata dipping towards the horizon are liable to be cut through and to slip. A skilful piece of engineering, with reference to this, was performed on the London and Birmingham Railway. In excavating through a hill, the strata were cut through and began to slip; so the Engineer immediately caused a tunnel to be turned, and allowed the earth to slide over the top. Alternating strata of clay and sand require effectual draining. In marshy soil, a new artificial bed must sometimes be formed by replacing the spongy soil with harder materials. In sidelong ground, it often becomes necessary to form steps for a foundation.

Fig. 3.

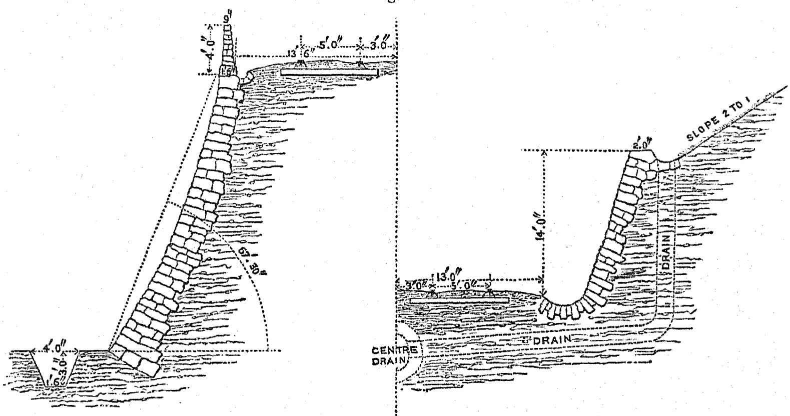


Section of an Embankment.

During the construction and after the completion of earthworks, the main cause of slips is the presence of water, either from springs or otherwise, which must be carried off by drains; the subsoil also should be drained, either by a drain under the centre of the roadway or by side ditches. In wet seasons, all soils require the greatest caution.

Gravel and sand are the best materials for embankments, as they consolidate rapidly and are easily drained. Shaly earth, when hard and dry, is also good. Dry clay mixed with straw, though long in consolidating, forms sometimes a sound embankment. Vegetable mould, soft shaly earth, wet clay and peat, are unfavourable. In crossing Chat Moss, which is of peat, Mr. Stephenson formed the embankment of the moss itself dried. In cases of very deep bogs, in Ireland, Sir John Macneill has used for a foundation a raft formed of layers of young trees, crossing each other. It is generally considered advisable, in embankments, not to make the base of the slope less than twice its height; and when stone is plentiful or land dear, a revetment wall may be advantageously substituted for a slope.

Fig. 4.



Section of an Embankment. Section of a Cutting.

When the levels of the line and the slopes for the cuttings and embankments have been determined on, the cubic content of earthwork must be calculated; for which purpose numerous Tables have been constructed. The following, framed by H. Law, Esq., C. E., and published in 1845, are concise and applicable to all descriptions of excavation. (*For the method of using these Tables, see p.* 189.)

TABLE I.

	LENGTH IN CHAINS.									
	1	2	3	4	5	6	7	8	9	
1	1·222	2·444	3·667	4·889	6·111	7·333	8·556	9·778	11·00	1
2	2·444	4·889	7·333	9·778	12·22	14·67	17·11	19·56	22·00	2
3	3·667	7·333	11·00	14·67	18·33	22·00	25·67	29·33	33·00	3
4	4·889	9·778	14·67	19·56	24·44	29·33	34·22	39·11	44·00	4
5	6·111	12·22	18·33	24·44	30·56	36·67	42·78	48·89	55·00	5
6	7·333	14·67	22·00	29·33	36·67	44·00	51·33	58·67	66·00	6
7	8·556	17·11	25·67	34·22	42·78	51·33	59·89	68·44	77·00	7
8	9·778	19·56	29·33	39·11	48·89	58·67	68·44	78·22	88·00	8
9	11·00	22·00	33·00	44·00	55·00	66·00	77·00	88·00	99·00	9
10	12·22	24·44	36·67	48·89	61·11	73·33	85·56	97·78	110·0	10
	1	2	3	4	5	6	7	8	9	
11	13·44	26·89	40·33	53·78	67·22	80·67	94·11	107·6	121·0	11
12	14·67	29·33	44·00	58·67	73·33	88·00	102·7	117·3	132·0	12
13	15·89	31·78	47·67	63·56	79·44	95·33	111·2	127·1	143·0	13
14	17·11	34·22	51·33	68·44	85·56	102·7	119·8	136·9	154·0	14
15	18·33	36·67	55·00	73·33	91·67	110·0	128·3	146·7	165·0	15
16	19·56	39·11	58·67	78·22	97·78	117·3	136·9	156·4	176·0	16
17	20·78	41·56	62·33	83·11	103·9	124·7	145·4	166·2	187·0	17
18	22·00	44·00	66·00	88·00	110·0	132·0	154·0	176·0	198·0	18
19	23·22	46·44	69·67	92·89	116·1	139·3	162·6	185·8	209·0	19
20	24·44	48·89	73·33	97·78	122·2	146·7	171·1	195·6	220·0	20
	1	2	3	4	5	6	7	8	9	
21	25·67	51·33	77·00	102·7	128·3	154·0	179·7	205·3	231·0	21
22	26·89	53·78	80·67	107·6	134·4	161·3	188·2	215·1	242·0	22
23	28·11	56·22	84·33	112·4	140·6	168·7	196·8	224·9	253·0	23
24	29·33	58·67	88·00	117·3	146·7	176·0	205·3	234·7	264·0	24
25	30·56	61·11	91·67	122·2	152·8	183·3	213·9	244·4	275·0	25
26	31·78	63·56	95·33	127·1	158·9	190·7	222·4	254·2	286·0	26
27	33·00	66·00	99·00	132·0	165·0	198·0	231·0	264·0	297·0	27
28	34·22	68·44	102·7	136·9	171·1	205·3	239·6	273·7	308·0	28
29	35·44	70·89	106·3	141·8	177·2	212·7	248·1	283·6	319·0	29
30	36·67	73·33	110·0	146·7	183·3	220·0	256·7	293·3	330·0	30

TABLE I.—(CONTINUED.)

	LENGTH IN CHAINS.									
	1	2	3	4	5	6	7	8	9	
31	37·89	75·78	113·7	151·6	189·4	227·3	265·2	303·1	341·0	31
32	39·11	78·22	117·3	156·4	195·6	234·7	273·8	312·9	352·0	32
33	40·33	80·67	121·0	161·3	201·7	242·0	282·3	322·7	363·0	33
34	41·56	83·11	124·7	166·2	207·8	249·3	290·9	332·4	374·0	34
35	42·78	85·56	128·3	171·1	213·9	256·7	299·4	342·2	385·0	35
36	44·00	88·00	132·0	176·0	220·0	264·0	308·0	352·0	396·0	36
37	45·22	90·44	135·7	180·9	226·1	271·3	316·6	361·8	407·0	37
38	46·44	92·89	139·3	185·8	232·2	278·7	325·1	371·6	418·0	38
39	47·67	95·33	143·0	190·7	238·3	286·0	333·7	381·3	429·0	39
40	48·89	97·78	146·7	195·6	244·4	293·3	342·2	391·1	440·0	40
	1	2	3	4	5	6	7	8	9	
41	50·11	100·2	150·3	200·4	250·6	300·7	350·8	400·9	451·0	41
42	51·33	102·7	154·0	205·3	256·7	308·0	359·3	410·7	462·0	42
43	52·56	105·1	157·7	210·2	262·8	315·3	367·9	420·4	473·0	43
44	53·78	107·6	161·3	215·1	268·9	322·7	376·4	430·2	484·0	44
45	55·00	110·0	165·0	220·0	275·0	330·0	385·0	440·0	495·0	45
46	56·22	112·4	168·7	224·9	281·1	337·3	393·6	449·8	506·0	46
47	57·44	114·9	172·3	229·8	287·2	344·7	402·1	459·6	517·0	47
48	58·67	117·3	176·0	234·7	293·3	352·0	410·7	469·3	528·0	48
49	59·89	119·8	179·7	239·6	299·4	359·3	419·2	479·1	539·0	49
50	61·11	122·2	183·3	244·4	305·6	366·7	427·8	488·9	550·0	50
	1	2	3	4	5	6	7	8	9	
51	62·33	124·7	187·0	249·3	311·7	374·0	436·3	498·7	561·0	51
52	63·56	127·1	190·7	254·2	317·8	381·3	444·9	508·4	572·0	52
53	64·78	129·6	194·3	259·1	323·9	388·7	453·4	518·2	583·0	53
54	66·00	132·0	198·0	264·0	330·0	396·0	462·0	528·0	594·0	54
55	67·22	134·4	201·7	268·9	336·1	403·3	470·6	537·8	605·0	55
56	68·44	136·9	205·3	273·8	342·2	410·7	479·1	547·6	616·0	56
57	69·67	139·3	209·0	278·7	348·3	418·0	487·7	557·3	627·0	57
58	70·89	141·8	212·7	283·6	354·4	425·3	496·2	567·1	638·0	58
59	72·11	144·2	216·3	288·4	360·6	432·7	504·8	576·9	649·0	59
60	73·33	146·7	220·0	293·3	366·7	440·0	513·3	586·7	660·0	60

	LENGTH IN CHAINS.									
	1	2	3	4	5	6	7	8	9	
61	74·56	149·1	223·7	298·2	372·8	447·3	521·9	596·4	671·0	61
62	75·78	151·6	227·3	303·1	378·9	454·7	530·4	606·2	682·0	62
63	77·00	154·0	231·0	308·0	385·0	462·0	539·0	616·0	693·0	63
64	78·22	156·4	234·7	312·9	391·1	469·3	547·6	625·8	704·0	64
65	79·44	158·9	238·3	317·8	397·2	476·7	556·1	635·6	715·0	65
66	80·67	161·3	242·0	322·7	403·3	484·0	564·7	645·3	726·0	66
67	81·89	163·8	245·7	327·6	409·4	491·3	573·2	655·1	737·0	67
68	83·11	166·2	249·3	332·4	415·6	498·7	581·8	664·9	748·0	68
69	84·33	168·7	253·0	337·3	421·7	506·0	590·3	674·7	759·0	69
70	85·56	171·1	256·7	342·2	427·8	513·3	598·9	684·4	770·0	70
	1	2	3	4	5	6	7	8	9	
71	86·78	173·6	260·3	347·1	433·9	520·7	607·4	694·2	781·0	71
72	88·00	176·0	264·0	352·0	440·0	528·0	616·0	704·0	792·0	72
73	89·22	178·4	267·7	356·9	446·1	535·3	624·6	713·8	803·0	73
74	90·44	180·9	271·3	361·8	452·2	542·7	633·1	723·6	814·0	74
75	91·67	183·3	275·0	366·7	458·3	550·0	641·7	733·3	825·0	75
76	92·89	185·8	278·7	371·6	464·4	557·3	650·2	743·1	836·0	76
77	94·11	188·2	282·3	376·4	470·6	564·7	658·8	752·9	847·0	77
78	95·33	190·7	286·0	381·3	476·7	572·0	667·3	762·7	858·0	78
79	96·56	193·1	289·7	386·2	482·8	579·3	675·9	772·4	869·0	79
80	97·78	195·6	293·3	391·1	488·9	586·7	684·4	782·2	880·0	80

	LENGTH IN CHAINS.									
	1	2	3	4	5	6	7	8	9	
81	99·00	198·0	297·0	396·0	495·0	594·0	693·0	792·0	891·0	81
82	100·2	200·4	300·7	400·9	501·1	601·3	701·6	801·8	902·0	82
83	101·4	202·9	304·3	405·8	507·2	608·7	710·1	811·6	913·0	83
84	102·7	205·3	308·0	410·7	513·3	616·0	718·7	821·3	924·0	84
85	103·9	207·8	311·7	415·6	519·4	623·3	727·2	831·1	935·0	85
86	105·1	210·2	315·3	420·4	525·6	630·7	735·3	840·9	946·0	86
87	106·3	212·7	319·0	425·3	531·7	638·0	744·3	850·7	957·0	87
88	107·6	215·1	322·7	430·2	537·8	645·3	752·9	860·4	968·0	88
89	108·8	217·6	326·3	435·1	543·9	652·7	761·4	870·2	979·0	89
90	110·0	220·0	330·0	440·0	550·0	660·0	770·0	880·0	990·0	90
	1	2	3	4	5	6	7	8	9	
91	111·2	222·4	333·7	444·9	556·1	667·3	778·6	889·8	1001	91
92	112·4	224·9	337·3	449·8	562·2	674·7	787·1	899·6	1012	92
93	113·7	227·3	341·0	454·7	568·3	682·0	795·7	909·3	1023	93
94	114·9	229·8	344·7	459·6	574·4	689·3	804·2	919·1	1034	94
95	116·1	232·2	348·3	464·4	580·6	696·7	812·8	928·9	1045	95
96	117·3	234·7	352·0	469·3	586·7	704·0	821·3	938·7	1056	96
97	118·6	237·1	355·7	474·2	592·8	711·3	829·9	948·4	1067	97
98	119·8	239·6	359·3	479·1	598·9	718·7	838·4	958·2	1078	98
99	121·0	242·0	363·0	484·0	605·0	726·0	847·0	968·0	1089	99
100	122·2	244·4	366·7	488·9	611·1	733·3	855·6	977·8	1100	100

TABLE II.

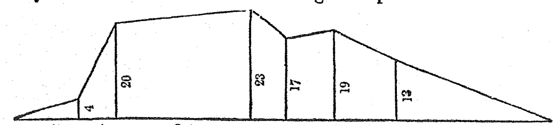
	LENGTH IN CHAINS.									
	1	2	3	4	5	6	7	8	9	
1	·4074	·8148	1·222	1·630	2·037	2·444	2·852	3·259	3·667	1
2	1·630	3·259	4·889	6·518	8·148	9·778	11·41	13·04	14·67	2
3	3·667	7·333	11·00	14·67	18·33	22·00	25·67	29·33	33·00	3
4	6·518	13·04	19·56	26·07	32·59	39·11	45·63	52·15	58·67	4
5	10·18	20·37	30·56	40·74	50·92	61·11	71·29	81·48	91·67	5
6	14·67	29·33	44·00	58·67	73·33	88·00	102·7	117·3	132·0	6
7	19·96	39·93	59·89	79·85	99·81	119·8	139·7	159·7	179·7	7
8	26·07	52·15	78·22	104·3	130·4	156·4	182·5	208·6	234·7	8
9	33·00	66·00	99·00	132·0	165·0	198·0	231·0	264·0	297·0	9
10	40·74	81·48	122·2	163·0	203·7	244·4	285·2	325·9	366·7	10

	LENGTH IN CHAINS.									
	1	2	3	4	5	6	7	8	9	
11	49·29	98·59	147·9	197·2	246·5	295·8	345·1	394·3	443·7	11
12	58·67	117·3	176·0	234·7	293·3	352·0	410·7	469·3	528·0	12
13	68·85	137·7	206·6	275·4	344·3	413·1	482·0	550·8	619·7	13
14	79·86	159·7	239·6	319·4	399·3	479·1	559·0	638·8	718·7	14
15	91·67	183·3	275·0	366·7	458·3	550·0	641·7	733·3	825·0	15
16	104·3	208·6	312·9	417·2	521·5	625·8	730·1	834·4	938·7	16
17	117·7	235·5	353·2	471·0	588·7	706·4	824·2	941·9	1060	17
18	132·0	264·0	396·0	528·0	660·0	792·0	924·0	1056	1188	18
19	147·1	294·1	441·2	588·3	735·4	882·4	1029	1177	1324	19
20	163·0	325·9	488·9	651·8	814·8	977·8	1141	1304	1467	20

TABLE II.—(CONTINUED.)

	LENGTH IN CHAINS.									
	1	2	3	4	5	6	7	8	9	
21	179·7	359·3	539·0	718·7	898·3	1078	1258	1437	1617	21
22	197·2	394·4	591·6	788·7	985·9	1183	1380	1577	1775	22
23	215·5	431·0	646·6	862·0	1078	1293	1509	1724	1940	23
24	234·7	469·3	704·0	938·7	1173	1408	1643	1877	2112	24
25	254·6	509·2	763·9	1018	1273	1527	1782	2037	2292	25
26	275·4	550·8	826·2	1102	1377	1652	1928	2203	2479	26
27	297·0	594·0	891·0	1188	1485	1782	2079	2376	2673	27
28	319·4	638·8	958·2	1278	1597	1916	2236	2555	2875	28
29	342·6	685·3	1028	1370	1713	2056	2398	2741	3084	29
30	366·7	733·3	1100	1467	1833	2200	2567	2933	3300	30
	1	2	3	4	5	6	7	8	9	
31	391·6	783·1	1175	1566	1958	2349	2741	3132	3524	31
32	417·2	834·4	1252	1669	2086	2503	2920	3337	3755	32
33	443·7	887·3	1331	1775	2218	2662	3106	3549	3993	33
34	471·0	941·9	1413	1884	2355	2826	3297	3768	4239	34
35	499·1	998·1	1497	1996	2495	2994	3494	3993	4492	35
36	528·0	1056	1584	2112	2640	3168	3696	4224	4752	36
37	557·7	1115	1673	2231	2789	3346	3904	4462	5020	37
38	588·3	1177	1765	2353	2941	3530	4118	4706	5295	38
39	619·7	1239	1859	2479	3098	3718	4338	4957	5577	39
40	651·8	1304	1956	2607	3259	3911	4563	5215	5867	40
	1	2	3	4	5	6	7	8	9	
41	684·9	1370	2055	2739	3424	4109	4794	5479	6164	41
42	718·7	1437	2156	2875	3593	4312	5031	5749	6468	42
43	753·3	1507	2260	3013	3766	4520	5273	6026	6780	43
44	788·7	1577	2366	3155	3944	4732	5521	6311	7099	44
45	825·0	1650	2475	3300	4125	4950	5775	6600	7425	45
46	862·1	1724	2586	3448	4310	5172	6034	6897	7759	46
47	900·0	1800	2700	3600	4500	5400	6300	7200	8100	47
48	938·7	1877	2816	3755	4693	5632	6571	7509	8448	48
49	978·2	1956	2935	3913	4891	5869	6847	7825	8804	49
50	1018	2037	3056	4074	5092	6111	7129	8148	9167	50

Note.—The method of using the Tables will be rendered perfectly clear by an examination of the following example.



7 × 4 × 14 × 3 × 5 × 6 × 18

Width of the line 30 feet. Slopes $1\frac{1}{2}$ to 1.

L	H	h	Content of trunk from Table I.	H × h	Content of one slope. (a) From Table I.	Content of one slope. (b) From Table II.
Chains.	Feet.	Feet.	Cubic yds.		Cubic yds.	Cubic yds.
7	4	—	34·2	—	——	45·6
4	20	4	117·3	80	391	417·2
10 } 4 }	23	20 {	525·6 } 210·2 }	460 {	5622 2249	36·7 14·7
3	23	17	146·7	391 {	1430 } 3 }	44·0
5	19	17	220·0	323 {	1956 } 18 }	8·1
6	19	13	234·7	247 {	1760 } 51 }	88·0
10 } 8 }	13	— {	158·9 } 127·1 }	— {	—— {	688·5 550·8
			1774·7		13480	1893·6
			30		1893·6	
			53241		15373·6	
			46120·8		3	
Total Contents			99361·8		46120·8	

METHOD OF USING THE TABLES.

For the Trunk or Central Part in a Cutting or Embankment.—Add together the height in feet of the two ends; then look for this No. in the first column of Table I., and on the same line, under the proper length in chains, will be found the content in cubic yards. Should the length exceed 9 chains, the content must be taken out in two operations. The content thus obtained is for 1 foot only in width; the total quantity must be multiplied by the true width in feet.

For the Slopes on the Side of a Cutting or Embankment.—If the embankment has a height at only one end, the content in cubic yards is given at once in Table II.; the height in feet being contained in the outside vertical columns.

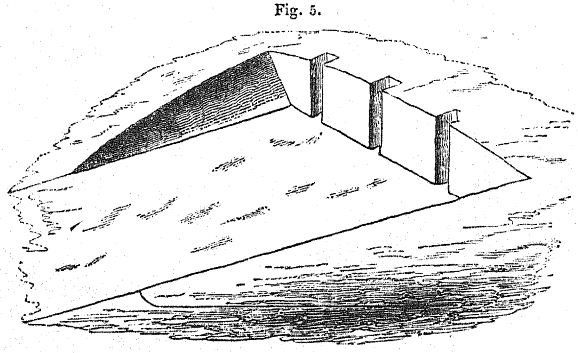
If the embankment has a height at each end, multiply the two heights together; look for this No. in the outside column of Table I., and take out the No. on the same line under the proper length (*a*). Then subtract the lesser height from the greater; look for this No. in the first column of Table II., and take out the No. on the same line under the proper length (*b*). These two (*a* and *b*) added together will give the content in cubic yards, for any length not exceeding 9 chains: when greater than that, it must be taken out in two operations. The content thus obtained is for one side only, calculated upon a slope of 1 to 1: the total quantity must be doubled; and for any other slope, must be multiplied by the ratio of the base to the height.

If the lengths are in feet instead of chains, these Tables may equally well be used, by taking the figures in the top line as feet, and dividing the total result by 66. (*See example, p.* 188.)

The main art of directing earthworks consists in so proportioning the men to each task, and disposing the *matériel* or plant, that none shall for a moment stand idle, and that a free passage shall be continually kept open. These proportions depend upon local circumstances, and can scarcely even approximately be made the subject of calculation, but, together with the disposition of the men, depend on the judgment of the Engineer.

Cuttings.—In commencing an excavation, a face at right angles to the direction of cutting should be obtained, and a gullet, of about 15 feet wide, formed as soon as possible. The accompanying sketch shews a mode of cutting niches with the pick-

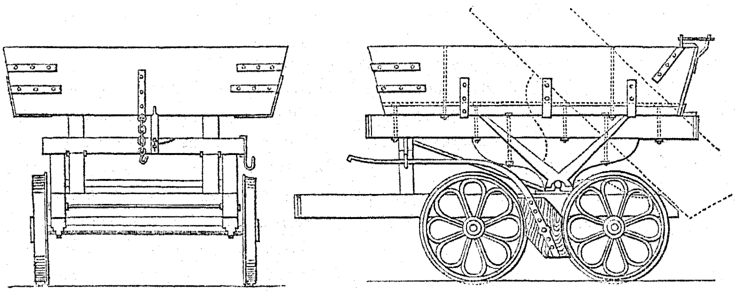
Fig. 5.



axe, and a very little labour enables the excavator to separate the masses between. Into the gullet, when formed, a train of waggons to receive the earth is sent. As the height of the hill increases, side tracks on a higher level are laid down, and the inclines which connect them with the first line serve to enable the loaded carriages to draw up the empty ones. Plate XXVIII. shews the above-described method.

Embankments.—The ordinary mode of embanking is to run out to the full height required at once, but the operation may be carried on with equal if not greater rapidity by forming a bank of half the required height, and following this up closely with an upper bank to the full height, just so much narrower as will allow waggons to pass to the head of the lower one. The most expensive but at the same time the most solid mode is to form the bank in successive shallow layers, each being run out and allowed to consolidate before the one above is commenced. Plate XXIX. shews the arrangements which may be adopted for leading the waggons to the head of the embankment, and the accompanying sketch (fig. 6) shews a front and side elevation of a waggon.

Fig. 6.



It may be assumed that at the average rate of wages of the present day, and with contract work conducted as efficiently as it is in this country, the following prices will give a fair idea of the cost of earthwork, viz.:

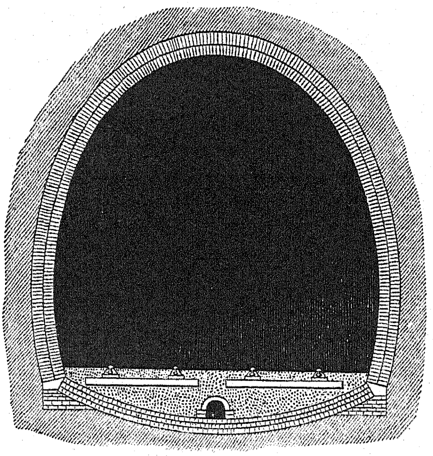
	Average. *s.*	*d.*
Excavating, carrying, and forming into embankment, with any lead not exceeding half a mile, not rock . from 9*d.* to 1*s.* 3*d.* per cubic yard,	1	0½
Do., do., hard close rock . . . . from 1*s.* to 4*s.* do. do.	2	4½
Excavation from tunnel, all plant being found by the contractor, from 5*s.* to 7*s.* do. do.	6	2
If the lead exceeds half a mile, the following would be the addition to the price, according to the distance, for every fractional part of a mile: at the rate per mile of . . . . from 4*d.* to 8*d.* do. do.	0	5¼
Turfing, soiling, and sowing slopes (including cost of stripping and setting aside, such not being paid for in the earthwork), 10 inches thick, from 2*d.* to 8*d.* per sq. yard,	0	4¼
Metalling surface of new roads . . . . from 1*s.* to 3*s.* do. do.	1	11½
Metalling surface of temporary divisions, including contingencies, from 1*s.* to 2*s.* do. do.	1	7

Temporary fencing, from 1*s.* 6*d.* to 2*s.* per foot run.

Tunnel.—The advantage of substituting a tunnel for a cutting, or a viaduct for an embankment, will depend chiefly on local circumstances, as the surplus or deficiency of the material excavated, the price of land, and the geological formation of the country. (See fig. 7.)

The expense of a tunnel will depend upon the strata through which it is to be carried, and on the absence or presence of water: as this circumstance can seldom be foreseen, it is almost impossible to form a correct estimate, but careful borings, previous to commencing the work, will be found very useful.

Fig. 7.



Section of Tunnel, shewing Drainage.

The following prices shew how much they vary in expense, viz.

Name of Tunnel.	Price per yard.	
Birkenhead Tunnel (single line)	£32	in red sandstone
Box Tunnel, on Great Western, ...	100 ,,	oolitic rock
Bletchingley, South Eastern, ...	72	
Cheltenham	34	
Clay Cross, North Midland, ...	100	
Grovely Hill, Bristol and Birmingham, . . .	32 ,,	marl
Kilsby, London and North Western, ...	125	
Leeds, Leeds and Selby, ...	25 ,,	shale & coal measures
Lime Street, Liverpool, ...	80 ,,	red sandstone
Royston, North Midland, ...	50 ,,	red sandstone
Saltwood, South Eastern, ...	118	
Summit, Manchester and Leeds, ...	97	
Whiteball, Exeter, ...	53	

The expense of the Kilsby and Saltwood tunnels was increased by meeting with large quantities of water.

It may be mentioned here, that in tunnelling through chalk, '*pot-holes*' are frequently met with, which are cylindrical shafts, worn apparently by the rotatory action of water and stones, and filled generally with gravel or some other foreign substance; and the removal of the chalk from below the bottom of these, leaving only a thin shell to support them, frequently causes their contents to break through, and occasionally to do serious damage to the tunnel.

Viaducts.—In the construction of viaducts, either instead of embankments or to carry a railway over roads, rivers, &c., Engineers appear to concur in considering that brick and stone are the most desirable materials to use; but questions of economy, and the necessity of crossing large spans with a level soffit, often compel them to adopt wood and iron: and where the foundations are treacherous, as in the mining districts, or where the substrata are compressible, a flat soffit affords capabilities for repair which are highly advantageous.

Although it does not properly fall within the present limits to describe the numerous varieties in the modes of construction of bridges to which the rapid extension of railways has given rise, it does appear desirable to state the effect which velocity has on bridges subject to deflection in increasing the strain due to a given weight.

Effects of Velocity on Bridges subject to Deflection.—If a weight be laid upon a beam supported at each end by props, it will produce a deflection; this deflection will be greatest at or near the centre, but the greatest curvature will occur at the point where the weight is suspended. If the weight be made to traverse the beam with rapidity, it may be conceived that an additional effect due to the motion of the body in a curve will be produced, and that the re-action of the beam would be the resultant of this additional force, which would act in the direction of the radius of curvature and of the force of gravity. This re-action of the beam may be resolved into two forces, one acting in the direction of the tangent to the beam, the other at right angles to it; and this latter force would represent the tendency of the bar to break. It will, upon consideration, be evident that the additional effect above mentioned would vary directly with the square of the velocity and the deflection, and inversely with the length of the beam. The mathematical investigation of this question is extremely complicated. The following is a short sketch of the mode of solution adopted by Professor Willis and Professor Stokes, and given at full length in the Appendix to the Report of the Commissioners for inquiring into the Application of Iron to Railway Structures.

It may be deduced, from what previous writers on the strength of materials have said, that if a weight be suspended from a beam (the inertia of the beam being neglected, and the weight considered as a heavy moving point), and if the deflection at the point of suspension $= y$, and the distance of the point from the end of the bar $= x$, the half-length of the bar $= a$, and the weight suspended $=$ W; then $y = c\,\mathrm{W}\,(2\,a\,x - x^2)^2$, when c is a constant quantity dependent upon the elasticity and transverse section of the bar. Now if M be the mass of the weight, S the central statical deflection, or deflection produced by the weight when at rest, and R the re-action between the body and the bar (which, as the deflection is small, may be supposed to act vertically), the elastic re-action of the bar at any point (its inertia being neglected) is equal to the weight which, when suspended at that point, would depress it to the same distance below the horizontal line. Therefore, $\mathrm{R} = \mathrm{W} = \frac{y}{c} \cdot \frac{1}{(2\,a\,x - x^2)^2}$; and if $x = l$, or half the length of the bar, y becomes equal to S; and if $\mathrm{R} = \mathrm{M}\,g$ (when g represents the force of gravity), $c = \frac{\mathrm{S}}{\mathrm{M}\,g\,.\,a^4}$. Now if the weight be supposed to move with a velocity $=$ V, the forces which act on the body are its gravity and the re-action of the bar. Whence is obtained the equation of motion,

$$\frac{d^2 y}{d\,t^2} = g - \frac{g\,a^4}{\mathrm{S}} \cdot \frac{y}{(2\,a\,x - x^2)^2};$$

which, since $\mathrm{V} = \frac{d\,x}{d\,t}$, becomes

$$\frac{d^2 y}{d\,x^2} = \frac{g}{\mathrm{V}^2} - \frac{g\,a^4}{\mathrm{V}^2\,\mathrm{S}} \cdot \frac{y}{(2\,a\,x - x^2)^2}.$$

The integration of this equation would give the form of the path of the body. But it cannot apparently be integrated in finite terms, except for an infinite number of particular values of a certain constant involved in it. This constant has been termed β, and $\beta = \frac{g\,a^2}{4\,\mathrm{V}^2\mathrm{S}}$; a small value therefore corresponds to a short bridge and

a high velocity, and a large value to a long bridge and a lower velocity. If we put $g =$ 32·2 feet, $l =$ length of bridge in feet, $V =$ velocity in feet per second, and $S =$ central statical deflection in inches, we shall have

$$\beta = 24{\cdot}15 \frac{l^2}{V^2 S}.$$

When β is large, the following series will express the ratio of the central deflection due to the moving weight $= D$, to the central statical deflection $= S$.

$$\frac{D}{S} = 1 + \frac{1}{\beta} + \frac{5}{2\beta^2} + \frac{13}{\beta^3} + \ldots$$

When β is equal to, or greater than 100, the first two terms of the series will be true to the third place of decimals; substituting therefore the value of β we obtain $D = S + \frac{4 V^2 S^2}{g a^2}$. Hence, for a given load, the increment of deflection due to velocity varies nearly directly as the square of the velocity, and inversely as the square of the length of the bridge. But this is on the supposition that the mass of the bridge is insignificant.

When the *inertia* is taken into account, the problem becomes so complicated that its complete solution seems to elude the present powers of analysis. It appears, however, that when β is less than about unity, the *inertia* will diminish the central deflection due to the moving weight. When β is greater than unity, the *inertia* will at first increase the deflection, and bring it to a maximum, and then diminish it. An approximate solution of this problem has been obtained by Mr. Stokes, for the two extreme cases in which the mass of the body or mass of the bridge are neglected; and although in the cases similar to those in practice, where the masses are very nearly equal, the effects are so mixed up together as not to be as yet fully developed, the following Table, which has been calculated empirically, will serve to shew roughly the increments of statical deflection due to different conditions of bridges, until further experiments and a perfected theory shall have determined the question more exactly.

In the following Table, $l =$ length of bridge in feet, $V =$ velocity of moving weight in feet per second, $S =$ central statical deflection, or deflection due to the weight at rest on the centre.

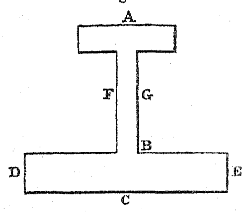
Values of $24{\cdot}15 \frac{l^2}{V^2 S}$.	5	6	8	10	15	20	25	30	40	50	100	200
Increments of S when mass of bar is neglected.	·30	·23	·18	·14	·10	·06	·05	·04	·03	·02	·01	·005
Increments due to the inertia.	·25	·22	·19	·17	·14	·12	·11	·10	·09	·08	·05	·04
Total increments of statical deflection.	·55	·45	·37	·31	·24	·18	·16	·14	·12	·10	·06	·045

To apply this Table to any given bridge, the statical deflection due to the greatest load which is liable to pass over it must be ascertained, and also the greatest probable velocity: from these data, and from the length of the bridge, the value of $\frac{l^2}{V^2 S}$ must be calculated. The increment of statical deflection which corresponds

to this value will be found in the lower line of the Table; and since for small deflections the strain may be considered to increase with the deflection, the greatest load to which the bridge could be practically exposed should be diminished in the proportion of the total increment of statical deflection in the Table.

Strength of Iron.—The cheapest and most prevalent description of iron bridges in use upon railways is the simple cast-iron girder bridge, and the form usually adopted is that recommended by Mr. Hodgkinson, the top and bottom flanges being made parallel for convenience, and the sectional area of the bottom flange being made from four to six times greater than that of the top, on the assumption that the strength of cast iron to resist a tensile force is less than its strength to resist a crushing force in that proportion; and the breaking weight may be calculated from the following formula, where W = breaking weight in the middle of the beam, l = distance between the supports, in feet, a = area of section of bottom flange in the middle, d = depth of beam in the middle,—

Fig. 8.



$$W = \frac{2{\cdot}166\, a\, d}{l};$$

or, if the effect of the vertical part between the flanges is included, and d = A C = whole depth, d' = A B = depth to bottom flange, b = D E = breadth of the bottom flange, b' = F G = thickness of the vertical part,

$$W = \frac{2}{3\, b\, d\, l}\left\{ b\, d^3 - (b - b')\, d'^3 \right\}.$$

The following formulæ, expressing the relation between the extension and compression of cast iron, and the weight producing them respectively, are given in the Report of the Commission on the Application of Iron to Railway Structures, viz.

$$\text{For extension, } w = 13934040\,\frac{e}{l} - 2097432000\,\frac{e^2}{l^2},$$

$$\text{For compression, } w = 12931560\,\frac{d}{l} - 522979200\,\frac{d^2}{l^2},$$

where w = weight per square inch of section, l = length of bar in inches, e = extension in inches, d = compression in inches.

Formulæ have, however, been derived by Mr. Tredgold from the same experiments, which appear to be more convenient in calculating the strength of beams, from the consideration of the forces of extension and compression acting round the neutral axis: the formulæ are—

$$\text{For extension,}\quad w = \frac{14173080\, e}{l + 288{\cdot}84\, e},$$

$$\text{For compression, } w = \frac{13002840\, d}{l + 51{\cdot}6\, d}.$$

The mean tensile strength of cast iron is 15711 lbs. per square inch, and the ultimate extension $\frac{1}{600}$ of the length: this weight would compress a bar of cast iron of the same section $\frac{1}{775}$ of its length. The general ratio of the power of cast iron to resist tension to that to resist compression is 1 : 5·6603. In wrought iron the extensions and compressions with equal weights are nearly equal, and a rod will extend ·01124 inch for each foot in length with a weight of 11 tons per square inch. Up to this weight the extension may be assumed to vary nearly with the weights; but

beyond it the elasticity is considerably injured. Cast iron is decreased in length by compression about double the amount that wrought iron is with equal weights, whilst the ultimate strength of cast iron to resist compression is twice or three times as great as that of wrought iron. Cast iron will not bear reiterated flexure due to more than ⅓rd of its breaking weight; and on account of the concussions to which it is exposed in railway bridges, it is considered that the ultimate strength of cast-iron girders should be equal to three times the permanent load, and six times the greatest moving load that could come upon the bridge. Judging from the structures of the most eminent Engineers, it would appear that they consider 5 tons per square inch as the greatest strain to which wrought iron should be permanently exposed in railway bridges. The strength of plates of wrought iron, when compressed to resist buckling, will vary nearly as the cube of their thickness up to about 9 tons per square inch; beyond this the metal becomes injured, and the increase of strength will be more nearly in proportion to the thickness. Riveting, when executed in the best manner, will reduce the tensile strength of wrought-iron plates to about ⅔rds. Long-continued impact on riveted tubes, producing a deflection of less than one-fifth of what would be required to injure the tube by pressure, was shewn by Mr. Hodgkinson's experiments to be totally destructive to the riveting.

Bridges.—The dimensions for bridges over roads will of course be regulated by the nature of the traffic upon them: in this country, unless other sizes are provided by the Special Act, the Railway Clauses Consolidation Act allows the following minimum dimensions, viz. For a turnpike-road, the height from the ground to the springing of the arch, 12 feet; height to the crown of the arch, 16 feet; span, 35 feet: for a public carriage-road the height must be 15 feet to the crown of the arch, and the span 25 feet; and for a private carriage-road the height must be 15 feet, and the span 12 feet. By the same Act, the steepness of the approaches to bridges is also regulated, viz. The greatest slope for a turnpike-road is 1 in 30; for a public carriage-road, 1 in 20; and for a private carriage-road, 1 in 16. It should, however, be remembered that whilst a moderate incline would be very severely felt where the adjacent roads are level, in hilly country it would scarcely be perceived.*

The average cost of bridges, including the approaches, in this country, may be roughly assumed at — for turnpike-roads, £2000 each; for public carriage-roads, from £1000 to £1500; and for farm or occupation roads, from £300 to £500 each.

The following list of prices for buildings, &c., may be considered as an approximate average of the cost in this country:

	Average. £	s.	d.
Masonry—of fitted rubble set in mortar, including all erections, centering, scaffolding, excavation of foundations, backing, and all contingent work necessary in the construction of tunnels, ... from 25*s.* to 45*s.* per cubic yard,	1	13	0
Ditto —arches, spandril walls, or parapets of culverts, or any other work not exceeding 2 feet in thickness, from 16*s.* to 25*s.* do. do.	0	19	0
Ditto —retaining walls, wing walls, and abutments, and all work exceeding 2 feet in thickness, ... do. do.	1	2	0
Ditto —of common rubble in boundary walls, from 10*s.* to 14*s.* do. do.	0	12	0
Brickwork—set in mortar, including all erections, centering, scaffolding, excavation of foundations, backing, and all contingent work necessary in the construction of tunnels, from 28*s.* to 32*s.* do. do.	1	10	0

* Tables shewing the ratio in which the quantities of material for bridges increase with the increase of height are given in the article 'Passage of Rivers,' p. 76.

	Average. £	s.	d.
Brickwork—arches, spandril walls, or parapets, or in culverts, or all work not exceeding $2\frac{1}{2}$ bricks in thickness, from 17*s.* 6*d.* to 35*s.* per cubic yard,	1	4	0
Ditto —retaining walls, wing walls, and abutments, and all work exceeding $2\frac{1}{2}$ feet in thickness, . . from 14*s.* to 30*s.* do. do.	1	0	0
Addition to above, if set in Roman cement, . from 5*s.* to 10*s.* do. do.	0	7	6
Ditto ditto for tunnel, from 2*s.* to 7*s.* do. do.	0	4	6
Coping of brick, set in cement, . . from 1*s.* 6*d.* to 2*s.* per cubic foot,	0	1	9
Block stone in courses, set, ... do. do.	0	1	6
Coping string-courses in stone, dressed and set, from 2*s.* to 3*s.* 6*d.* do. do.	0	3	0
Ashlar, ditto ditto . . . . do. do.	0	3	4
Concrete, including excavation, ... from 6*s.* to 10*s.* per cubic yard,	0	8	0
Timber-work—fir-framed, creosoted, carried and fixed in place, including pile-driving and all contingencies, from 3*s.* 3*d.* to 5*s.* do. do.	0	3	6
Wrought iron—fixed and painted, . . . from £18 to £38, do. do.	27	0	0
Cast iron—fixed and painted, . . . from £10 to £17 10*s.* do. do.	12	0	0

Level Crossings.—Safety requires that level crossings should be used as rarely as possible. When unavoidable, the line should be visible for some distance on each side, and a police-man or gate-keeper should be stationed at every crossing of a public road. In some cases, particularly where persons on the crossing cannot command a good view, or where the crossing is approached by a steep gradient on the railway, signals should be introduced. The average cost of a level crossing, with gates and a porter's lodge, is £450; a paved crossing, with gates for an occupation-road, will average £40. (See Plate III.)

The number of communications per mile across railways, taken from an average of 1200 miles, selected from different parts of the country, is 3·31, classed as follows: bridges over the railway, ·9 per mile; bridges under the railway, ·96; level crossings, 1·45.

Draining.—It is essential that the slopes and revetment walls of cuttings be well drained, as also the roadway. (See Plates I. II.) Water should be prevented from accumulating, and wherever it is known to exist, its immediate source should be traced, for it is to the neglect of this precaution that most failures of works can be attributed. In solid earth or rock, good ditches will suffice for the side drains; but where depth is required, or where the earth is soft or wet, the sides must be revetted. The expense of culverts may be supposed to average £400 per mile.

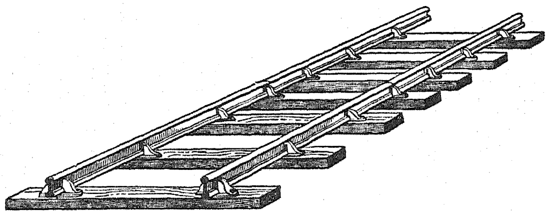
Formation.—The width of the formation varies from 28 to 31 feet, and the centre is usually raised from 3 inches to 6 inches above the sides, for the sake of drainage.

Permanent Way.—The permanent way comprises the ballasting with the rails and their supports; in fact, all between the formation and rail level. The ballast should be generally not less than 18 inches in thickness between the formation level and the sleepers carrying the rails, but this depth varies with the nature of the substratum on which it is placed; its use being, in bad soil, to produce a distribution of the rolling weight over a larger surface than that immediately beneath the sleeper, and to keep the latter dry. For this purpose, the formation should have been first carefully formed with side ditches, and sloping from the centre towards both sides. Too much attention cannot be devoted to this subject, as much of the permanent cost of working depends upon the goodness or otherwise of the permanent way, one principal

element in the maintenance of which is a well-drained substratum upon which it may rest.

Rails.—Rails, as laid at present, may be classified under two general forms, the requirements of which are somewhat different according to the means of support adopted. The double-headed rail, modifications of which are shewn in Plates IV. V., has been generally used upon bearings at varying distances formed by sleepers 9 feet long, with a section of *not less* than about 30 square inches: between each of these sleepers, the rail forms a bridge upon which the wheels travel. In this case the rail requires such a depth and section that the passing

Fig. 9.

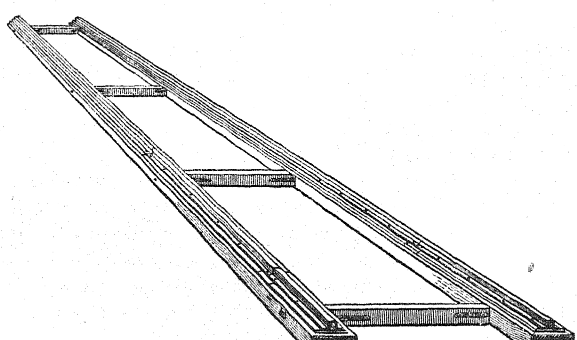


Edge-Rail, with transverse Sleepers.

weights shall produce no great deflection, even though by an inequality in the road, or other cause, the weight of a pair of wheels is thrown upon one rail, and an occasional bearing be absent or defective. The weight, according to present practice, to be provided against may be taken as 5 tons upon one wheel, so that 10 tons should not produce a great deflection at a double distance or interval. It is obvious that in every description of permanent way, the joint of the rail must be the weakest point, as far as the rail itself is concerned, and will require therefore to be specially strengthened by artificial means. In the transverse sleeper road, these means are provided by shortening the bearings, or bringing the sleepers nearer to each other as they approach the joints, and by placing larger sleepers or chairs under the joints.

The other class of rail in general use is known under the name of the bridge-rail, being of the form shewn in Plate VI. It is usually placed upon longitudinal sleepers or bearers, which have a continuous bearing upon the ballast, and therefore it does not require to be so strong and stiff as that used with supports having

Fig. 10.



Bridge-Rail, with longitudinal Bearings.

intervals or spaces between them. The sleeper and rail in this case form a joint beam, and under the supposition that they are everywhere adequately supported, no strain is brought upon them beyond the mere crushing force of the rolling weight. This, however, cannot well be the case in practice, as no perfectly incompressible substance can be placed under the sleepers; and hence the effect of the rolling weight is at length to permit a small depression throughout the whole length of the rail, which causes the wheel, as it were, to be always working against an ascending or curved incline. In this description of permanent way, the timber sleepers are generally 14″ × 7″ in section, breaking joint with the rails and with the sleepers of the opposite rails, and they are kept apart and in proper relative position as to cant by cross timbers or transoms notched in between them at every 10 or 15 feet (the shorter distance applies to curves), to which straps of iron are bolted, the bolts passing through the sleepers, and being fixed by nuts and washers on the outside, to prevent the rails from spreading. The rails are fastened to the longitudinal bearers by bolts passing through both, having large-headed fanged nuts on the under side, the fangs or prongs serving to hold the nut firmly to the timber, and short plates of wrought iron are placed under the joints, to prevent them from working into the timber. By this it will be seen, that supposing the rails to be 16 feet in length, and the gauge or width between the rails 4 feet 8½ inches, there will under each line of railway, for a single length of rail, be an area bearing upon the ballast of 37 feet, requiring about 22½ cubic feet of timber.

Supposing the transverse sleepers to be adopted, five in number to each length of rail, and 9 feet in length, in order to afford an equal bearing upon the ballast, they should be 10 inches wide; and taking them at 6 inches in depth, which is the least that should be adopted, 18¾ cubic feet will be required for 16 feet of railway: this is under the supposition that the whole of each sleeper bears upon the ballast, which in practice is never found to be the case, as the plate-layers usually pack up the ends of the sleepers and leave the middle untouched. Now, from what has been before stated, the bridge-rail does not require to be so stiff and strong as the rail upon supports at intervals, and it may be assumed, that a rail weighing 60 ℔s. per yard upon the former is as effective as one weighing 70 or 75 ℔s. upon the latter; and again, the latter requires cast-iron chairs for seating it upon the sleepers, which generally average about one-third the weight of the rail, with a slight addition in weight to the chair which contains the joints of the rails; so that, as regards the expense of material, it appears that upon a gauge of 4 feet 8½ inches, the rail upon continuous bearings is cheaper than that upon supports at intervals. As regards efficiency, the question between the two systems admits of some doubt: the continuous bearing is probably more difficult of removal in case of decay, but its maintenance whilst its materials last is less expensive, as the joints, when properly and carefully laid, are not so difficult to maintain. Upon the stability and condition of the permanent way depends in a great measure the expense of the working of the railway. Inequalities in the road may be considered as synonymous with increase of power, in proportion to weight moved, with reduction in speed when like weights are moved, and in both cases increased wear and tear upon the moving stock; and in proportion as the moving weights become unsteady, the difficulty and consequent expense of properly maintaining the road increases, each acting upon the other in a direct proportion. It is evident, therefore, that the solidity and good construction of the permanent way are of the first importance; and to establish it, the following points are those principally to be attended to:

1st. The draining of the *formation* surface.

2ndly. The nature of the ballast, which should be easily permeable by water, and at the same time have a sufficiency of fine materials to bind it together to a certain

extent.* It should not be of so light a nature as to produce dust, or to be easily raised by the current produced by passing trains, or by wind, and so get into the working parts of the engine or the axle-boxes of the carriages, and also incommode travellers. When broken stone can be obtained, it may be considered to form the best ballast, provided a few inches of gravel or very small stone be laid between it and the timber.

3rdly. The smoothness of the joints of the rails, to effect which care should be taken that the rails are square-butted and well seated on the chairs or longitudinal timbers, and so fixed that in expanding and contracting from the effects of temperature, the intervals between the rails shall not much vary: these intervals are often increased in the case of transverse sleepers by the effect of the traffic passing always in one direction and drawing the rail in the direction of motion. The perfection of a permanent way is for every part to be alike in solidity and smoothness; and for this purpose the attention of the Engineer should be especially directed to the joints, which are naturally the weakest points in the rails. When railways were first commenced, machinery not being so perfect as it is at present, it was found impracticable to obtain rails of sufficient weight of greater lengths than 15 or 16 feet; but by improvements in the process of manufacture they may now be procured of nearly double that length. It is therefore advisable, in determining the rails for a railway, to ascertain to what lengths rails of the required weight can be rolled, and to adopt those of the greatest length, even at an increased cost, as the joints or weak parts decrease in the ratio of the length of each rail, and there is a corresponding reduction in the means to be applied to stiffen the joints, and in the labour necessary to maintain them. In the comparison of the two systems, it should not be omitted that the continuous bearing has a *decided* superiority over the ordinary transverse sleeper road, by dispensing with the cast-iron chairs, which often break, with the oak keys used to fasten the rail in the chair: these keys, by the effect of the atmosphere (damp expanding and dry hot weather contracting them), are constantly varying even in the same day from tight to loose, and *vice versâ*, and are acted upon by the friction of the rail, which, in expanding, contracting, and deflecting, tends to move them, so that they are a constant source of anxiety, and require to be examined *daily* at least once, and, where there is a night traffic, twice. It is a very common thing for the key of the joint chair to work clear of the joint, and so leave the rail at that point without lateral support, which must be highly dangerous to passing trains. To obviate the evil arising from this, it has been proposed to lay a flat bar of iron, extending between the chairs on each side the joint, in the chairs and touching the side of the rail, the oak key securing it in its place.

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* The following rates may be assumed as the approximate cost of ballasting in this country:

	Average per cubic yard. *s.*	*d.*
Excavating, carrying, depositing, and spreading material for ballast, . from 1*s.* 6*d.* to 3*s.*	2	$1\frac{1}{2}$
If obtained from the necessary excavation of permanent cutting, and paid for once as earthwork, and with a lead not exceeding half a mile, . . .	2	0
Broken stones or coarse ballast, ... from 1*s.* 6*d.* to 3*s.*	2	$2\frac{1}{2}$
Burnt clay, ... from 2*s.* 6*d.* to 4*s.* 6*d.*	3	6
Gravel or other fine ballast, ... from 1*s.* 2*d.* to 2*s.*	1	7
If obtained from side cuttings or elsewhere, and not otherwise paid for as earthwork:		
Broken stone for coarse ballast, ... from 2*s.* to 3*s.*	2	6
Burnt clay, ... from 3*s.* to 4*s.* 6*d.*	3	9
Gravel or other fine ballast, ... from 1*s.* 6*d.* to 2*s.* 6*d.*	2	0
If the lead exceeds half a mile, addition to the prices named, according to the increase of distance for any fractional part of a mile, at the rate per mile of from 4*d.* to 8*d.*	0	$5\frac{1}{4}$

The danger apprehended from the use of the chair and key has induced the introduction, on the Irish railways, by an eminent Engineer, of a system combining the two, the bridge-rail being spiked directly to transverse sleepers, by which means the chair is dispensed with.

Other Engineers have endeavoured to combine the two systems by placing transverse sleepers under the continuous or longitudinal bearers. This system appears fallacious, for practically the two are never equally packed, and so the longitudinal bearer and rail become a combined beam to support the rolling weight over the space between the transverse supports, which are in fact the piers of a series of small bridges; and unless the spans are small, this combined girder is found not to be sufficiently rigid.

To remedy the defects of existing permanent ways, and remove the perishable material, timber, which is found to be a costly item in the working expenses of railways, various schemes have been proposed, more especially of late; but as their respective merits have not yet been fully tested, it would be premature in this place to describe them. The above principles will, however, apply in considering them, which it is strongly recommended should be carefully done by any person about to commence an extensive work of this nature. The system patented by Mr. W. H. Barlow, Engineer to the Midland Railway Company, appears to afford the greatest promise of success as applied to a new line; in it the bridge-rail is extended to a width of about 15 inches, the bottom inclining downwards from the centre, as shewn in the accompanying figure, to prevent the ballast from spreading. It is proposed to make the joints by an iron chair of large dimensions and ties of broad wrought iron, but the details have not been fully worked out and tried: various plans, however, for executing them will suggest themselves readily to an ingenious mind. A cast-iron longitudinal sleeper, with chairs attached, has also been proposed, and it appears likely to be useful in enabling old lines to get their existing rails worn out without a constant expense for the removal of timber. This latter item has, however, been very much increased to them by sufficient care not having been taken in the selection of the timber in the first instance; and the defects in the timber, by allowing inequalities to arise in the roadway, have caused the rails to wear out much more rapidly than they otherwise would have done. In considering all the various systems of permanent way, it behoves Engineers in future to profit by the experience which has been already acquired, and, upon the facts to be adduced therefrom, either to adopt the best, or by combination and invention to produce a more perfect, road.

Fig. 11.

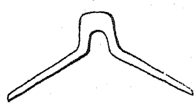
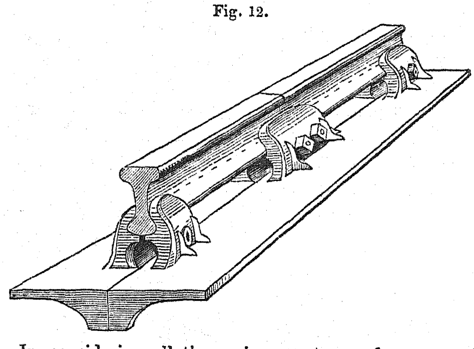


Fig. 12.



Qualities of Iron.—Under the head of permanent way, it appears necessary to draw attention to the manufacture of iron, as the quality of the metal is found to differ very materially; but as this is a subject in itself, those points only will be alluded to which require particular notice, and are *desiderata* in the manufacture of rails.

1st. Rails should not be of too *short* or *brittle* a nature.

2ndly. They should present a hard surface to the passing wheels.

3rdly. The pile should be carefully made to combine the last desideratum with a power to resist crushing or disintegration at the welds formed near the upper surface in rolling; or, in other words, they should not be liable to lamination.

4thly. The ends should be square-butted.

5thly. The rail should be straight, even, and uniform.

To ascertain, as far as possible, on obtaining rails, that due attention in their manufacture has been bestowed upon them, it would appear desirable to select a certain proportion, and, after having gauged them by templates and weighed them, to obtain their deflections under dead pressure, and their power to resist fracture by impact.

The weight to which rails can be rolled is limited only by the power of rolling the iron fibrous and sound: they have been rolled to more than 100 lbs. per yard. No accurate average of the wear and tear due either to the passage of trains or to the weather has been published; but the destruction of the rail is generally due to lamination. To guard against this, it has lately been proposed to harden the upper surface of the rails, and render the lower flange fibrous by adding a small proportion of tin in the first case, and of calamine in the second, to the iron in the puddling furnace.

In laying the permanent way of a railway in those positions where it passes round curves, it is considered advisable, in order to diminish the resistance, to lay the rails slightly wide in gauge, to the extent of probably a quarter of an inch, and by raising the outside rail to counteract the centrifugal force consequent upon the movement of the train in a curve. To estimate the amount of this, if v' represent the velocity of the carriage in feet per second, and r' represent the radius of the curve in feet, the effect due to the centrifugal force will be $\frac{v'^2}{2r'}$; and if $x =$ the super-elevation of the outer rail, and $w =$ width of gauge (expressed in the same denomination as the super-elevation), which, as x is small, may be assumed equal to the length of the inclined plane formed by super-elevating the outer rail,—then, since a body would fall 16·1 feet in a second by gravity alone, $16{\cdot}1\,\frac{x}{w} =$ tendency of the body to slide down the inclined plane by which the centrifugal force is to be counteracted.

Therefore, to determine the super-elevation of the outer rail,

$$\frac{x}{w} \times 16{\cdot}1 = \frac{v'^2}{2\,r'} \text{ or } x = \frac{w\,v'^2}{32{\cdot}2\,r};$$

and if $v =$ velocity in miles per hour,
and r = radius of curve in chains,

we shall obtain $x = \frac{v^2}{1000\,r}w$, nearly.

Hence the super-elevation of the outer rail increases directly with the width of gauge and the square of the velocity, and inversely with the radius of curvature; and, theoretically, the limit to which it can be carried appears to be the point at which packages in goods carriages moving at low velocities would not be liable to displacement. When the super-elevation of the outer rail is great, and must be attained gradually, the curvature at each point should be proportioned to the elevation, and this would form a curve approaching to a parabola. If, instead of considering the rails laid down in a curve, each rail be looked upon as the side of a polygon inscribed

in a circle whose radius is the radius of curvature, as is generally the case in practice with rails when first laid, different conditions will ensue; but it is found that by use the rails soon assume the form of a curve.

Practically, the limit to which the super-elevation of the outer rail can be carried, is about 4 inches on the narrow, and 6 inches on the broad gauge, and the elevation of the rail is commenced on the tangent before the curve is entered upon. The distances usually allowed between the lines of rails in a double railway is 6 feet, which amply provides for the security of carriages and trucks of the construction in *ordinary* use on railways in England.

Points and Switches.—In order to pass from one line of rails to another, cross-over roads are introduced (see Plates V. VII.): these should in all cases be placed near stations, in order that the points may be under the surveillance of trustworthy persons,—as indeed should be all points: a drawing of Wild's patent point or switch, apparently combining all the advantages of those in general use, is given in Plate V.

Points should in double lines be placed so that trains in passing over them, in the right direction of the traffic on the line on which they are moving, cannot leave their line without backing, either to pass into a siding, or into the opposite line of way. This remark does not apply to junctions or even to principal sidings, on lines of very heavy and continuous traffic, where the intervals between the trains are very short, and where the obstruction produced by stopping a train and moving it backwards to get into a siding or on to another line of rails, may produce risk of a collision. This latter, however, is a case that can only rarely occur, and almost exclusively in situations where, from the inclination of the railway, it becomes necessary to move the train backwards, or *shunt* against the gradient.

Turn-tables.—To enable single carriages to be shifted from one line of rails to another, and to enable engines and tenders to be turned round, *turn-tables* are used. They are practically formed of a pair of girders of sufficient length to receive the wheels of a carriage, braced together, and revolving round a pivot; and hence simplicity and strength are the main desiderata in their construction. They are generally from 11 feet to 13 feet in diameter, and those for turning an engine and tender without uncoupling, 30 feet in diameter. The small ones have usually been made of cast iron, but lately boiler-plate, strengthened with angle iron, has been proposed by Mr. P. W. Barlow. Great solidity in the foundation, to insure an equal bearing, is required, and the tables may revolve on rollers or on shot. A pair of iron girders or wooden beams, braced together and supported at the centre and ends on rollers, to which rack and pinion work is attached, form a good substitute for a turn-table. Rolling platforms are occasionally used to transfer carriages from one line of rails to another. (See Plates VIII. IX. X. XXVI. XXVII.)

Sidings.—Sidings, or branch railways, for the reception of trains or carriages which are required to be off the main line, are provided at or near stations, as well as, at intervals, on railways with only a single line of rails: except near the points of junction, they should be at least 6 feet distant from the main line, as should also be all parallel lines of rails.

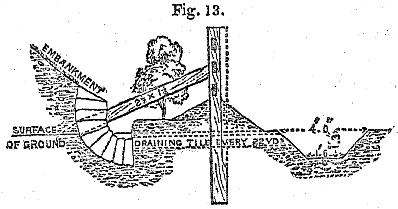
Signals.—The question of signals on railways is one of paramount importance; for the freedom of trains from accidents when moving at high velocities depends greatly upon the facility with which signals are seen, and the efficiency with which they are worked. At all places on a railway where engines or trains are usually stopped, permanent signal-posts should be erected, by means of which easily intelligible signals may be made in each direction, and also at level crossings near curves or steep gradients, where, the view being obstructed, especial precautions are required. For these purposes

the *semaphore* signal has been found to answer remarkably well. In it an arm, painted red, extended thus,  signifies 'caution,' and thus,  signifies 'danger,' or 'stop,'—the arm being suffered to hang down vertically to signify that the line is clear and all is right for an approaching train to proceed. These arms are usually made to work simultaneously with and by means of the same handle as lamps,—a green light being shewn to represent 'caution,'—a red light, 'danger,'—and a white light to signify 'all right.' As an auxiliary to these signals, additional posts with arms are now very generally placed at 600 and even 800 yards from the principal stopping-places, so as to give timely notice to engine-drivers of any obstruction, in case of fogs or hazy weather. These signals are easily worked from a lever by wires laid by the side of the railway, supported on friction rollers fixed to short posts. When required to be carried round curves, lateral rollers are also used, the limit to the distance at which these signals can be placed being the extent of view of the man who works them at the lever. It is very desirable that in all cases, where practicable, the signals at a station should be all under the control of one man. In addition to the above-mentioned signals, hand signals, such as flags or lamps, green, red, and white, are used; and a code of signals is also adopted for plate-layers and labourers, &c., such as waving a hat in a particular manner, or placing the body in a particular position. And in foggy weather, detonating signals, to be fixed to the rail and fired by the wheel of the engine, are of great service, as well as torches stuck in the ground and set to burn for ten minutes or a quarter of an hour.

Fencing.—The fencing should be sufficient to prevent all animals from straying upon the railway, and may consist of a sunk wet fence, a stone wall, a close well-grown quickset hedge, a post and rail, or any other material which may suggest itself as being efficient and at the same time most economical, and will vary with the locality and the means afforded by it.

The cost, at the present time in England, of permanent fencing of posts and four rails, creosoted, including ditches, but without quicking, one side only, may be assumed to vary from 2*s.* 4*d.* to 3*s.* 3*d.* per foot run; average 2*s.* 10*d.*

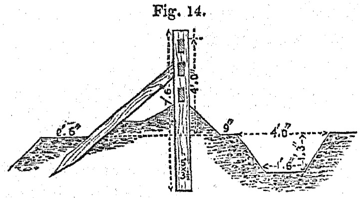
Fig. 13.



Section of a Ditch and Rail at an Embankment.

Stations (Plates XI. XII. and XIII.)—The number, position, and size of the stations will depend upon the nature, extent, and occupations of the surrounding population; and their judicious adaptation to local circumstances will exercise an important influence on the development of traffic on the line. In towns they should be conveniently accessible from leading thoroughfares; and in selecting their positions in the country, great judgment is required to plan them so as to accommodate the largest amount of population. The average number of stations on the lines at present open for traffic in Great Britain is one in every three miles.

Fig. 14.

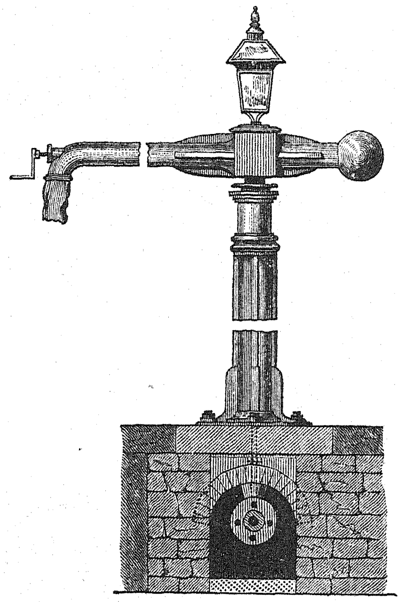


Section of a Ditch and Rail at an Excavation.

The accommodations of the stations should be such as to suit the requirements of

the traffic, and should afford a ready means of taking up and depositing passengers, luggage, goods, cattle, carriages, &c., &c., if necessary; as, on account of the expense, it may not be desirable to provide for all these conveniences at every station; and it may be observed, that in general the requirements cannot be ascertained before the opening of a railway, and the consequent development of the traffic. As on this last account stations frequently require increased accommodation from time to time, it is advisable in the first instance to obtain ample space, and to construct the station on a plan capable of being enlarged. In addition, however, to these considerations respecting the traffic, others, connected with the working of the line, must operate with the Engineer in the choice of position and the construction of the stations. Supplies of water for the engines should be provided at about every twenty miles, depending on the means of obtaining it, on the gradients, and on the class of engine employed. The water is usually conveyed into the tender by means of a water-crane, of which a drawing is given in Plate XXV. and figs. 14 *a* and 14 *b*, and, to economize fuel, is frequently heated previously. A renewal of the supply of fuel is similarly required. When it can be done, it is desirable to place a station on a level so situated as to have descending gradients on each side, which facilitates the stopping and starting of the trains. Details of construction are not given here, as they are equally applicable to other buildings; but it may be observed, that the principal requirements, in addition to the offices, are large spaces under cover for the platforms, the carriages, &c., as also stables for spare engines (see Plate XII.),—and, at particular places, workshops for the repair of the stock, &c. Hence has arisen the introduction of roofs of large span, in which lightness and cheapness of construction are the main points to be attended to. These considerations, together with the large space required for a station, point out as the most eligible site (*cæteris paribus*) one with an even surface on the level of a railway, as that would involve the least amount of labour to adapt it to its object.

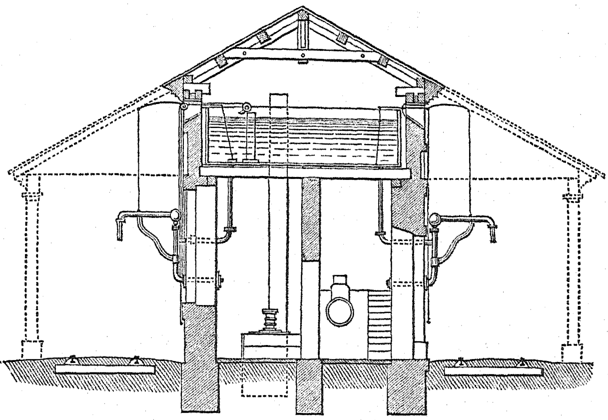
Fig. 14 *a*.



Bracket Water-Crane.

It would be beyond the intention of this article to describe the mode of fitting up and the articles required for the workshops for the repair of engines, carriages, &c., as they are similar to those required for other purposes. It may, however, be desirable to notice the mode of making coke, as the expense of locomotive power is materially dependent upon the cost of the fuel. The process of coking appears to free the coal from the impure gases and volatile parts, and from a proportion of the sulphur contained in it; and although the heating power of coke is less than that of coal, coke is used in locomotive engines on account of its freedom from smoke, and, consequently, not blocking up the tubes of the boiler. Coal also cakes, and requires

Fig. 14 *b*.



Water-Crane supplied from Cistern above.

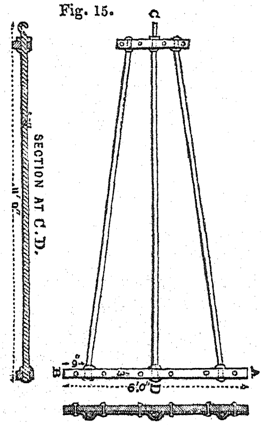
to be frequently stirred, whilst coke will remain for a long time in an ignited mass, through which the air can pass; and hence a different construction of grate is required for each.

The best description of coals for coking is stated to be the poorer sort, and not the rich coals adapted to household use. Freedom from sulphur is also desirable.

Coking ovens should be placed (when it is determined by a Railway Company to erect them) on that part of the railway where coal is cheapest. Plates XIV. and XV. exhibit a plan and sections of a coking oven, on what is believed to be the best and most approved construction.

To make Coke.—After the completion of the ovens, they are gradually heated by a slow fire, to dry the brickwork and cause evaporation: by degrees, the fire is increased for about seven or eight days, at which time the oven is ready to receive the first charge of coals. The coal is placed in the oven on an iron cradle, shewn in plan and section in the accompanying sketch. This cradle is used to assist the discharge of the ovens, and is of a shape to diminish the liability of the coke catching in the sides of the oven. When charged, the mouth of the oven is bricked up with fire-bricks without mortar, and the doors (which are of iron) closed, and the sides and top and bottom and centre division plastered over with fire-clay to exclude the air: the coal gradually ignites, the draught being regulated according to circumstances, as the state of wind, &c., by brick dampers, shewn at the top (see Plate XV.), which require to be constantly looked after. To assist the kindling, and prevent it from being the outer layer of coals alone which becomes ignited, the *bottom draught*, shewn in Plate XIV., is left open until the fire reaches the proper height, after which it is closed at the option of the burner. This draught is also required to allow the foul air to escape. The *top draught*, to carry off the evaporation, is left open for about five-sixths of the time of burning. When the

Fig. 15.



SECTION AT A B.

whole mass is red-hot, and an almost smokeless flame issues from it, which, after continuing for some time, gradually decreases, it is time to discharge the oven. The coke is then drawn out, and water thrown over it to quench it. As soon as the coke has been removed, the ovens are refilled with coal, which the heat of the ovens is sufficient to ignite: 48 hours are sufficient to convert some sorts of coal into coke, whilst others require 96 or 120 hours. The loss of weight in converting coal into coke is about 40 per cent., *i. e.* a given weight of coals will become about two-thirds the weight as coke.

The following are the particulars relating to some ovens built at Bridgewater, by the Bristol and Exeter Railway Company, on the principle shewn in the drawings: the labour of coking amounts to 11*d.* per ton; and

1 ton of Cardiff coal produces		13	cwt.	of coke.
"	"	6	"	waste.
"	"	½	"	small coke of no value.
"	"	½	"	ashes fit for lime-burning.
		20	cwt.	

Electric Telegraph.—The electric telegraph,* from the facilities it affords for transmitting messages, &c., has become so integral a part of the efficient working of railways, that it appears desirable to mention here some particulars connected with it. Various methods have been proposed for making and registering the signals: that most commonly in use in Great Britain is the Needle Telegraph, on which the signals are read off and written down at the rate of from about seventeen to twenty-five words per minute. In America, various modes of self-registering telegraphs have been proposed. The wires are carried alongside of the railways by earthenware supports attached to posts. The number of the wires is proportioned to the expected number of messages, and while some are reserved for the through communication, others are applied to the intermediate stations, and which may be put in connection with each other, or with branch lines, by means of turn-plates. The wires are covered with gutta-percha, to isolate them in passing through tunnels or near buildings, but in other places they have no covering; and in consequence, in very damp weather, it sometimes happens that the circuit, instead of being completed at the station the message is intended for, is completed along one of the other wires; and any increase to the force of the battery only tends to render this more certain in such cases. Messages can almost always be transmitted to a distance of 100 miles, but a clear state of the atmosphere is required to transport a message 300 miles. The needles are subject to disturbances from magnetic storms, for which a correction is introduced into the machines, and during thunder-storms they are liable to be demagnetized, should the lightning strike the wires: to obviate this, however, conductors have been introduced.

Working Stock.—The term 'rolling stock,' or working stock on a railway, implies the *matériel* for conveying the traffic, and includes engines, carriages, horse-boxes, trucks, goods-waggons, cattle-waggons, ballast-waggons, &c. Its cost depends so entirely upon the nature and amount of the traffic, that no estimate of it can be given. In Great Britain, however, the cost on the principal lines now in operation has averaged from £2000 to £3000 per mile.

Under the head of 'rolling stock' should be included the stationary plant, or machinery and tools in the workshops, which afford means of repair.

Carriages, Waggons, &c. (Plates XVI. to XXIV.)—The forms and dimensions of

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* See article 'Telegraph, Electric.'

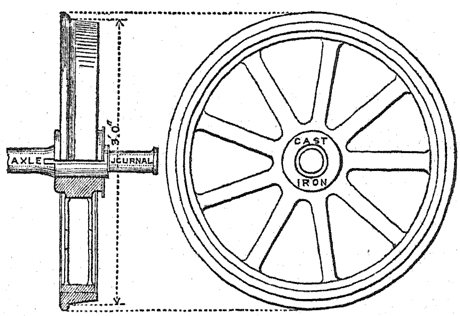
the various parts of the carriages and waggons at present in use on railways is the result of their gradual adaptation to the required strength and fitness, and not of any previously laid down general rule; and the various improvements they have undergone appear to have rendered them well adapted to their purpose.

The description of rolling stock to be selected for a railway will depend upon the nature of the anticipated traffic; and in the following remarks it is intended to convey an idea of the main points to be attended to.

The general construction of carriages and waggons, and their proportions in the several trains, should be such as to bring the average load conveyed as near as possible to the maximum load. In the conveyance of goods this is comparatively easy, but the varying numbers and divided classes for passengers entail a great loss of space.

Wheels.—The wheels of railway carriages should be uniform: the proper size appears to depend upon the following conditions, viz. The power required for the draught of wheel carriages depends principally on the friction of the axles and the surface resistance of the road, both of which may be assumed as proportionate to the insistent weight: the wheels do not add to the weight on the axles, but they do to the weight on the road; hence, although an increase of diameter will not diminish the friction on the axles, it *may* increase the surface resistance; and hence there is a limit to the advantage to be derived from increasing the size of the wheels.

Fig. 16.



The accompanying figure shews the general form of a railway carriage wheel as at present in use, although the particular modes of construction, as to spokes, &c., vary so much as to render any description of them beyond the limits of this article. Solid wheels have been proposed with a view of diminishing the atmospheric resistance; but at high velocities the spokes would carry round with them the intermediate air. Numerous adaptations of the tires of wheels have been attempted to obviate the danger of accident from their breaking or flying off. It has not hitherto been found practicable to adapt the wheels to work independently of each other on the axles, which, if accomplished, would do away with a principal cause of resistance in going round curves. This resistance is, however, to a certain extent, diminished by the coning of the wheels.

Axles of Carriages.—The axles of railway carriages appear to be exposed to the following strains, viz.

1st, That arising from the weight of the waggon and load, which acts on the journal, and is increased by the momentum acquired by the load in falling through spaces caused by inequalities in the road.

2ndly, That arising from the oscillation of waggons on curves, due to imperfect coupling and to lateral play between the flanges of the wheels and the rails.

3rdly, That due to starting and stopping trains.

4thly, The torsion caused by the dragging of the wheels in going round curves, and by inequalities in the sizes of the wheels, or in their balancing, or in the journals, brasses, &c.

The axle is also subject to constant vibration.

From these causes it is most desirable that great care should be exercised in selecting the best fibrous iron for axles.

Springs.—The strain on the axles due to the inequalities in the road is diminished by the use of springs, which should be so proportioned as to sustain the load easily, yielding equally in all carriages with the maximum load, and sufficiently elastic to absorb the effect of the oscillation of the load; to assist which, therefore, the load should be distributed equally on each side of the carriages.

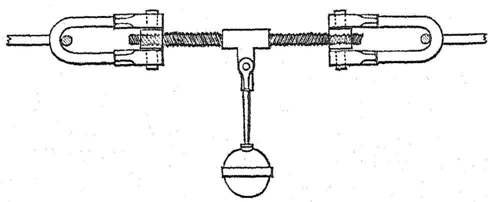
Axle-boxes.—The springs are connected with the journal by means of the axle-boxes. In some very long carriages which have been lately introduced on some lines of railway, the axle-box is allowed considerable lateral play on the journals, to enable these long carriages the more easily to pass round curves.

Framing.—The strength of carriages depends mainly on the mode in which they are framed, and the framing should be of similar construction for carriages intended to run in the same trains. The newest arrangements for timber framings are shewn in the accompanying Plates.

Coupling and Buffers.—To obviate the oscillations of carriages and waggons which produce strains on the axles and other parts, injury to the roadway, and deterioration to the loading, the connection between the carriages of a train should resemble as much as possible the jointing of the vertebræ in an animal's back-bone, by which means the lateral action of a carriage would be neutralized by the support of the neighbouring ones.

The buffers should be of the same size and height, and be constructed with springs; the carriages in a train should be coupled and drawn in the same manner by means of screw couplings and spring draw-bars; the draught acting always from the centre. The methods at present adopted for coupling and drawing the trains are, however, open to great improvement. The mode of coupling waggons in goods trains without spring buffers or draw-bars, and by a chain only, is liable to lead to accidents from the play which must necessarily be allowed between the waggons to admit of their going round curves; since each time the speed is slackened the waggons close up, and, at a fresh start, the chains are exposed to a sudden jerk. These jerks occasionally break the chains, which renders a double connection desirable, and they are also liable to become unhooked in stopping, but this would be obviated by a simple arrangement. It is not safe to place this description of waggon in passenger-trains, especially when running at high velocities.

Fig. 17.



Screw Coupling.

Passenger Carriages.—The arrangements for the parts of the carriages or waggons above the framing depend upon the description of the traffic for which they are intended. Those for passengers afford conveniences according to the class to be conveyed, and the classification will depend on the nature and habits of the population of the country. In Great Britain there are three classes, and the compartments of the carriages are small; whilst in America there is only one class, and a passage down the centre of the train renders the whole of the seats accessible from one end to the other. Wrought iron has latterly been used by several Railway Companies as a material for the construction of the upper portion of both carriages and waggons.

Cattle-Waggons.—The dimensions of cattle-waggons depend upon the description of stock and average load to be conveyed, whilst facilities should be afforded to persons who would load an entire waggon. The springs for the buffers and draw-bars in these and other goods-waggons are frequently made of vulcanized India-rubber.

Goods-Waggons. (Plates XXI. and XXII.)—For goods requiring care, high-sided covered waggons have been found so much more advantageous than open waggons, from affording security from the weather and from packages falling off, as well as effecting a saving in tarpaulins, as to compensate for their increased expense. For mineral traffic, the low-sided goods-waggons are generally in use, the weight of the waggon and load being usually limited to from six to eight tons.

The following Table will give an idea of the weight and cost of rolling stock, and may be assumed as a fair general average of prices, &c.

Description.	Weight.	Rate.
	Tons.	£
Locomotive engines and tenders, empty	18 / 7	2,200
1st-class carriages	3¼	300
2nd " "	3	220
3rd " "	3¼	200
Composite carriages, or 1st and 2nd class combined	4	600
4th-class carriages, without seats, separated by railing	3½	200
Post-office carriages and tenders	6	200
Trucks	3	120
Horse-boxes	3½	120
Goods-waggons	2½	100
Cattle and sheep cages	3	100
Iron hopper coal-waggons	2	70

Brakes.—To enable trains to be stopped in a moderate distance, brakes are applied to the wheels of some of the carriages, or guard-vans are attached to the trains. The number of brake-carriages or vans per train will depend on the inclinations on the line and the speeds employed: with passenger trains it has been considered that on an average, and to insure safety, every fifth carriage should have a brake: the engine also is generally reversed to assist the brakes. It must be recollected, however, that by stopping a train too rapidly, great injury results both to the permanent way and the rolling stock. (See Plate XXIII.)

The following considerations appear to be those which should determine the amount of brake-power.

The forces which act on the train after the steam has been shut off, are the axle friction and rolling friction of the train, and the pressure of the wind: the friction tends gradually to bring the train to rest,—the pressure of the wind to accelerate or retard it, as the case may be, and this will therefore be omitted from the conclusions to be drawn.

To stop a train rapidly, brakes are applied to some of the wheels, and the engine is reversed. The application of brakes prevents the wheels from revolving, and introduces the friction due to the weights on the wheels to which the brakes are applied. The act of reversing the engine does not immediately stop the forward motion of the driving-wheel, but forces it to revolve at a somewhat slower rate than that due to the speed of the train, and thus causes a friction of surfaces to take place between the wheel and rail.

The axle and rolling friction of the train may be assumed to be some proportion of the total weight of the train; the friction of the wheels to which brakes are

applied may be taken as some proportion of the insistent weights: from experiments,* it appears that the axle and rolling friction may be taken at $\frac{1}{334}$th part of the weight of the train, and the friction due to the brakes at about $\frac{1}{8}$th of the weights on them.

Hence, if l represent the gross load of the train,

w „ the weights on the wheels to which brakes are applied,

R „ the retardation in feet per second,

g „ the force of gravity,

and, if the train be on an incline,

$\frac{1}{p}$ represent the slope of such incline,

$$R = \left(\frac{l - w}{334} + \frac{w}{8} \pm \frac{l}{p}\right)\frac{g}{l},$$

the latter term being used with the negative sign when the train is descending and the positive sign when ascending the gradient.

If S = space traversed by the train in coming to rest,

v = velocity in feet per second at the moment the steam is shut off and the brakes applied,

$$S = \frac{v^2}{2R}.$$

In estimating practically the space which would be required for a train to stop in, one or two seconds should be allowed for time lost in applying the brakes.

Locomotive Engines.—Before proceeding to consider the cost of maintaining and of working a railway, it appears desirable to state the conditions upon which the powers of locomotive engines depend, and the principles which determine the form and class of engine to be selected for a particular line.

The dimensions of the several component parts of an engine will be regulated by the nature of the line it is to be employed upon, the description of the traffic, and the speed required.

The steam-power of an engine applied to the pistons is transferred to the load through the friction of the driving-wheel on the rail: as long, therefore, as the amount of steam at the required pressure which can be produced by the evaporation of water in the boiler is sufficient to counterbalance what is taken away for the cylinders, the adhesion of the driving-wheel on the rail will limit the load which can be drawn. But as the speed increases and the alternations of the pistons become so rapid as to take out the steam faster than it can be produced at the requisite pressure in the boiler, the pressure of the steam in the cylinders will diminish with the increased volume, and the pressure on the pistons will then limit the load.

With passenger traffic, or traffic at high speeds and with light loads, a large driving-wheel is advantageous; whilst with goods traffic, or traffic at low velocities, where heavy loads are drawn, it is usual to make all the wheels of equal size, and to couple them together, in order to obtain a larger amount of adhesion. The driving-wheels of the largest passenger engines in this country are made from 6 to 8 feet in diameter. Care must be taken so to arrange the parts of the engine with a large driving-wheel, that the centre of gravity shall be kept as low as possible. The wheels of goods engines are usually 5 feet diameter.

The area of the cylinders determines the amount of power which can be applied to the driving-wheel, but it is limited by the evaporative power of the boiler: the diameters of the cylinders of the largest engines now in use vary from 15 to 18 inches. The position of the cylinder has a great influence on the steadiness of motion in the

* Made in October, 1849, by Capt. Laffan, R. E.

engine, and this is conducive to safety, and diminishes the wear and tear upon the machinery and road. A horizontal cylinder, with a long connecting-rod, is the arrangement least liable to cause oscillation. The actual power applied to the pistons is diminished by the back pressure on the pistons, from the steam not having time to escape from the cylinder after the stroke and before the return of the piston: this will depend partly on the velocity of the piston, partly on the elasticity of the steam at the end of the stroke, and partly on the relative areas of the escape-pipe and cylinders. The whole power of the steam is only required to act upon the pistons when an engine begins to move from a state of rest, because when the velocity acquired becomes uniform, the power of the steam need only operate to overcome the friction which would otherwise soon cause the train to stop: hence, in order to diminish the back pressure, and also to economize fuel, it is usual to work engines expansively; that is, to cut off the steam when the piston has passed through a portion of the stroke, and allow the expansion of the steam to carry it through the remainder. The proportion of the length of the stroke at which it is considered advisable to cut off the steam depends upon the power of the boiler to generate steam, since the introduction of steam in an expanded state into the smoke-box renders the blast feeble, and diminishes the amount of steam generated by the boiler. The proportions will therefore vary with the relative size of the grate, boiler, and cylinder, as well as with the speed and power required to be exerted. With engines on the narrow-gauge lines it is usual to cut off the steam at from $\frac{5}{8}$ to $\frac{7}{8}$ of the stroke. In the 'Great Britain,' a broad-gauge engine, with an 18-inch cylinder and a 24-inch stroke, the steam is cut off at 18 inches when starting a heavy train,—at $16\frac{7}{8}$ inches when the full power of the engine is required, at from 40 to 50 miles per hour,—at $14\frac{3}{8}$ inches when the full power is required at higher speeds. The degree of nicety with which the motion of the slide-valve is timed relatively to the motion of the piston, operates strongly upon the consumption of the fuel.

The steam, after leaving the cylinder, is conveyed through the escape-pipe into the chimney, where, by forcing out the air, and then condensing it, it increases the draught of the fire,—the larger the amount of air displaced by the steam, the greater the blast created; whence it would appear that the lower the mouth of the escape-pipe is placed, the better,—remembering that it must be kept above the tubes of the boiler.

The evaporating power of the boiler will depend upon its size and form, as well as upon the size and form of the fire-box: the surface exposed to heat is increased by the use of tubes, the number of which will of course vary with their diameter; and this is determined by considering that while the smaller diameter increases the amount of surface exposed to heat, it tends to diminish the draught of the fire, and renders the tubes liable to be choked with dust. The diameter which has been generally adopted is about $1\frac{1}{2}$ inch internally. The tubes are of brass, and are found to wear out much more rapidly at the end adjacent to the fire-box than at the other end,—chiefly, it is supposed, on account of the small particles of coke carried through them by the draught. It would be beyond the limits of this article to enter upon the details of the component parts of locomotive engines, more particularly as the subject is to be treated under a separate head.* It is considered that 1 ℔. of coke usually evaporates 8 ℔s. of water,—or $1\frac{1}{4}$ ℔. of coke per gallon of water. The following Table shews the relation between the bulk, pressure, and temperature of steam.

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* See article 'Steam Engine.'—*Editors.*

Table of the Elastic Force of Steam, and corresponding Temperature of the Water with which it is in Contact.

Pressure on a square inch, including the pressure of the atmosphere.		Elastic force in		Temperature in degrees of			Volume of steam compared with the volume of water.	Pressure on a square inch, including the pressure of the atmosphere.		Elastic force in		Temperature in degrees of			Volume of steam compared with the volume of water.
lbs.	kilog.	Inches of mercury.	Metres of mercury.	Fahrenheit.	Reaum.	Cent.		lbs.	kilog.	Inches of mercury.	Metres of mercury.	Fahrenheit.	Reaum.	Cent.	
14·7	6·668	30·00	·762	212·0	80·0	100·0	1700	63	28·57	128·52	3·266	299·2	118·8	148·4	449
15	6·80	30·60	·778	212·8	80·4	100·4	1669	64	29·03	130·56	3·318	300·3	119·2	149·1	443
16	7·26	32·64	·829	216·3	81·9	102·4	1573	65	29·48	132·60	3·370	301·3	119·7	149·6	437
17	7·71	34·68	·880	219·6	83·3	104·2	1488	66	29·93	134·64	3·422	302·4	120·2	150·2	431
18	8·16	36·72	·932	222·7	84·7	105·9	1411	67	30·39	136·68	3·474	303·4	120·6	150·8	425
19	8·62	38·76	·984	225·6	86·0	107·6	1343	68	30·84	138·72	3·526	304·4	121·1	151·3	419
20	9·07	40·80	1·037	228·5	87·3	109·2	1281	69	31·29	140·76	3·577	305·4	121·5	151·9	414
21	9·52	42·84	1·089	231·2	88·5	110·7	1225	70	31·75	142·80	3·629	306·4	122·0	152·4	408
22	9·98	44·88	1·140	233·8	89·7	112·1	1174	71	32·20	144·84	3·681	307·4	122·4	153·0	403
23	10·43	46·92	1·192	236·3	90·8	113·5	1127	72	32·66	146·88	3·733	308·4	122·8	153·6	398
24	10·88	48·96	1·244	238·7	91·9	114·8	1084	73	33·11	148·92	3·785	309·3	123·2	154·1	393
25	11·34	51·00	1·296	241·0	93·0	116·1	1044	74	33·56	150·96	3·837	310·3	123·7	154·6	388
26	11·79	53·04	1·348	243·3	93·9	117·4	1007	75	34·02	153·02	3·889	311·2	124·1	155·1	383
27	12·25	55·08	1·400	245·5	94·9	118·6	973	76	34·47	155·06	3·940	312·2	124·5	155·7	379
28	12·70	57·12	1·452	247·6	95·8	119·8	941	77	34·93	157·10	3·992	313·1	124·9	156·2	374
29	13·15	59·16	1·503	249·6	96·7	120·9	911	78	35·38	159·14	4·044	314·0	125·3	156·7	370
30	13·61	61·21	1·555	251·6	97·6	122·0	883	79	35·83	161·18	4·096	314·9	125·7	157·2	366
31	14·06	63·24	1·607	253·6	98·5	123·1	857	80	36·29	163·22	4·148	315·8	126·1	157·7	362
32	14·51	65·28	1·659	255·5	99·3	124·2	833	81	36·74	165·26	4·199	316·7	126·5	158·2	358
33	14·97	67·32	1·711	257·3	100·1	125·2	810	82	37·19	167·30	4·252	317·6	126·9	158·7	354
34	15·42	69·36	1·763	259·1	100·9	126·2	788	83	37·65	169·34	4·303	318·4	127·3	159·1	350
35	15·87	71·40	1·814	260·9	101·7	127·2	767	84	38·10	171·38	4·355	319·3	127·7	159·6	346
36	16·33	73·44	1·866	262·6	102·5	128·1	748	85	38·55	173·42	4·407	320·1	128·0	160·1	342

37	16·78	75·48	1·918	264·3	103·2	129·1	729	86	39·01	175·46	4·459	321·0	128·4	160·6	339
38	17·23	77·52	1·970	265·9	104·0	129·9	712	87	39·46	177·50	4·511	321·8	128·8	161·0	335
39	17·69	79·56	2·022	267·5	104·7	130·8	695	88	39·91	179·54	4·563	322·6	129·2	161·4	332
40	18·14	81·60	2·074	269·1	105·4	131·7	679	89	40·37	181·58	4·615	323·5	129·6	161·9	328
41	18·59	83·64	2·126	270·6	106·0	132·6	664	90	40·82	183·62	4·666	324·3	129·9	162·4	325
42	19·05	85·68	2·178	272·1	106·7	133·4	649	91	41·27	185·66	4·718	325·1	130·3	162·8	322
43	19·50	87·72	2·229	273·6	107·4	134·2	635	92	41·73	187·70	4·770	325·9	130·6	163·3	319
44	19·96	89·76	2·281	275·0	108·0	135·0	622	93	42·18	189·74	4·822	326·7	131·0	163·7	316
45	20·41	91·80	2·333	276·4	108·6	135·8	610	94	42·64	191·78	4·874	327·5	131·3	164·2	313
46	20·86	93·84	2·385	277·8	109·2	136·6	598	95	43·09	193·82	4·926	328·2	131·6	164·8	310
47	21·32	95·88	2·437	279·2	109·9	137·3	586	96	43·54	195·86	4·977	329·0	132·0	165·0	307
48	21·77	97·92	2·489	280·5	110·4	138·1	575	97	44·00	197·90	5·029	329·8	132·4	165·4	304
49	22·22	99·96	2·541	281·9	111·1	138·8	564	98	44·45	199·92	5·081	330·5	132·7	165·8	301
50	22·68	102·00	2·592	283·2	111·6	139·6	554	99	44·90	201·96	5·133	331·3	133·0	166·3	298
51	23·13	104·04	2·644	284·4	112·2	140·2	544	100	45·36	204·01	5·185	332·0	133·3	166·7	295
52	23·59	106·08	2·696	285·7	112·8	140·9	534	110	49·89	224·40	5·703	339·2	136·5	170·7	271
53	24·04	108·12	2·748	286·9	113·3	141·6	525	120	54·43	244·82	6·222	345·8	139·5	174·3	251
54	24·49	110·16	2·800	288·1	113·8	142·3	516	130	58·97	265·23	6·740	352·1	142·3	177·8	233
55	24·95	112·20	2·852	289·3	114·4	142·9	508	140	63·50	285·61	7·259	357·9	144·8	181·1	218
56	25·40	114·24	2·903	290·5	114·9	143·6	500	150	68·04	306·03	7·778	363·4	147·3	184·1	205
57	25·85	116·28	2·955	291·7	115·4	144·3	492	160	72·57	326·42	8·296	368·7	149·6	187·1	193
58	26·31	118·32	3·007	292·9	116·0	144·9	484	170	77·11	346·80	8·814	373·6	151·8	189·8	183
59	26·76	120·36	3·059	294·2	116·5	145·7	477	180	81·65	367·25	9·333	378·4	153·9	192·4	174
60	27·21	122·40	3·111	295·6	117·2	146·4	470	190	86·18	387·61	9·851	382·9	156·0	194·9	166
61	27·67	124·44	3·163	296·9	117·7	147·2	463	200	90·72	408·04	10·370	387·3	157·9	197·4	158
62	28·12	126·48	3·215	298·1	118·3	147·8	456								

The largest engine on the narrow gauge will evaporate from 200 to 230 cubic feet of water per hour, and the largest which have been constructed for the broad gauge from 300 to 350 cubic feet. The following dimensions are stated to be those of the largest engines now in use.

GOODS ENGINES.

	Narrow gauge.	Broad gauge.
Diameter of cylinder	16 to 18 inches	16 inches.
Length of stroke	22 to 24 "	24 "
Diameter of driving-wheel	4 ft. 6 in. to 5 ft.	5 ft.

Wheels all coupled, with a weight of from 8 to 10 tons on each pair; total weight of engine about 24 to 30 tons.

PASSENGER ENGINES.

	Narrow gauge.	Broad gauge.
Diameter of cylinder	15 to 16 inches	18 inches.
Length of stroke	21 inches	24 "
Diameter of driving-wheel	6 ft. to 8 ft.	8 ft.
Weight on driving-wheels	8 to 14 tons	$10\frac{9}{10}$ tons.
Weight of engine	18 to 25 "	31 "

The weight on the driving-wheel should be regulated by the power in the cylinder to overcome the adhesion, and by the strength of the permanent way. The adhesion may be taken as high as $\frac{1}{6}$th the weight on the driving-wheels; but when the rails are slippery, it is sometimes as low as $\frac{1}{30}$th.

Resistances to Trains.—The resistance to which railway trains are exposed is an important subject of inquiry, but a sufficient number of experimental facts has not yet been collected to establish a perfect formula.

The resistance in calm weather may be considered to be made up of three parts: 1st, the friction of the wheels and axles of the train, which is independent of the velocity, but varies with the weight; 2nd, the resistance due to concussions and oscillations of the train, which will, it may be assumed, vary with the velocity and with the weight; 3rd, the resistance from the air, which will vary with the square of the velocity and the frontage area of the train.

Mr. Wyndham Harding, in a paper read to the Institution of Civil Engineers in 1846, deduced from experiments a formula combining all these points.

Taking the friction of the train at 6 ℔s. per ton, and putting

T = tons weight of the train,
V = velocity in miles per hour,
N = area of frontage,
·0025 ℔. = resistance from air per square foot of frontage, at 1 mile per hour,

and assuming the resistance from concussions at $\frac{V}{3}$, he called the resistance of the train $= \left(6 + \frac{V}{3} + \frac{V^2 \times \cdot 0025 \times N}{T}\right) T$. On a careful comparison of this formula, which was derived from experiments on the narrow-gauge lines, with some experiments made by Mr. Gooch on the Great Western Railway, in 1848, it appears probable that Mr. Wyndham Harding has assumed too high a value for the second term of his equation, since the difference between the formulæ would be more than compensated for by a difference in the character of the roads, and the experiments shew the great importance of easy motion in the engine and train, and a good road: besides, although the resistance from friction is independent of velocity, that due to abrasion, or the wearing away of surfaces, is not so; and this may to a certain extent enter into the first term: the effect of wind, also, on the side of the train will be considerable. On

the whole, therefore, it appears impossible to assume a formula which can be at all satisfactory before the several elements shall have been determined by more numerous experiments under varying conditions of weather and of permanent way.

In order, however, to form an idea of the steam-power an engine is required to exert in drawing a train, after being diminished by the back pressure, it may be assumed, firstly, that the friction of the engine gear is, when reduced to the circumference of the driving-wheel, about 6 ℔s. per ton weight of engine and tender, and 1 ℔. additional for each ton of load; secondly, the resistance of the train is made up partly of the journal friction of the axles,—partly of the resistance of the air to the rotation of the wheels and axles, which will vary with the velocity and dimensions of the wheels, —the rolling friction of the wheels on the rails,—and the atmospheric resistance of the train. This total train-resistance at low speeds is assumed to be 8 ℔s. per ton weight of the train, but it increases rapidly with the increase of velocity; the following being the mean of the results given by Mr. Wyndham Harding and Mr. Gooch in their respective statements on the subject, viz.

At 10	miles per hour	the resistance is	8 ℔s.	per ton.
„ 20	„	„	12 „	„
„ 30	„	„	16 „	„
„ 40	„	„	20 „	„
„ 45	„	„	22 „	„
„ 50	„	„	25 „	„
„ 55	„	„	27 „	„
„ 60	„	„	30 „	„

Working Expenses.—The receipts from the traffic of a railway must be devoted, first, to pay for the maintenance and working of the line,—next, to the interest on the sum borrowed to assist in its construction, whilst the surplus remains as profit to the projectors of the line.

The annual charge upon a railway is partly independent of the amount of traffic, and partly dependent upon it.

The first or fixed charge is made up of the expenses of keeping the stations, tunnels, viaducts, slopes, drains, and fences in repair; a part of the expense of re-laying or renewing the sleepers, rails, ballasting, &c.; and a proportion of the expenses of management, such as the salaries of officers, police, and points-men, which, though they increase with the traffic, do not increase in proportion to it.

The other or varying charge is composed of the engine-men and fire-men's wages; the consumption of coke, grease, oil, &c.; the repairs of the engines and carriages; the wages of guards, porters, &c.; a proportion of the expenses of management and the maintenance of the permanent way, so far as it is affected by the traffic.

Maintenance of Way.—The expense of maintenance of way varies considerably from circumstances, and is rather a charge dependent on the character of the line and its original mode of construction, than on the amount of traffic; for although an increase of traffic increases the cost of maintenance, the difference between a maximum and minimum traffic is of less importance than that due to other causes. In a dry climate this would not probably be so much the case, but in this country a great part of the deterioration is due to the weather, and the expense will therefore vary with the depths and heights of the cuttings and embankments, and with the nature of the soil through which the railway passes. When a line is first opened for traffic, the expenses will be greater on account of the consolidation of the works, and any increased charge from this cause, or from the failure of works, may be fairly placed to the cost of construction.

Unfortunately, sufficient attention has not been paid, or rather, sufficient details

have not been published, relative to the deterioration of the rails and sleepers, to enable any general information with respect to it to be given. It is considered, by one party, that after a certain period they must be entirely re-laid, and that the current repairs cannot perpetuate, but will only prolong, their existence; and therefore, that in addition to the annual outlay, a proportion of the cost of renewal should be set aside, so as to distribute the expense over the whole period of the duration of the rails;—whilst, on the other hand, and with an equal show of reason, it is urged, that from the great variety in the quality of both rails and sleepers, the annual number requiring repair would, after a few years, become uniform, and that therefore, after the first few years, it is not necessary to form any reserve fund for renewals. Among the chief causes of wear and tear of rails and sleepers are the great weights and high speeds now in use, which, in passing over the inequalities at the joints, produce a series of blows: it is probable that some new mode of laying the roadway, better calculated than the present one to resist it, will ere long be adopted.

Captain Huish, in a pamphlet he published in 1849, considers that the rails and chairs will last 20 years, and the sleepers, if creosoted, from 12 to 20 years; and he would lay aside from £50 to £60 per annum as a reserve fund for renewal. On the Belgian railways, where the speed and the traffic are much less than on English railways, it has been assumed that the rails and chairs would last 120 years, and that $\frac{1}{120}$th part of their value should be yearly laid aside,—the duration of the sleepers being not less than 12 years. It is probable that in some of the Colonies, with a favourable climate, moderate speeds, and a limited traffic, this assumption as to the average durability would not be far wrong.

Three men per mile may be assumed as a fair average of the number permanently employed as plate-layers, in adjusting the rails, &c.

Cost of Locomotive Power.—The expense on account of locomotive power depends upon the number of miles run by the engine, and is, to a great degree, independent of the weight of the train, except in extreme cases. The expenditure on different lines will vary with the facilities for obtaining coal and with the nature of the gradients.

The fuel consumed by an engine may be divided into that required for getting up the steam, the proportion consumed while standing in reserve, and that expended in drawing the load; and hence, in order to obtain the maximum return from an engine, not only is it necessary to proportion the load to its powers, but it is necessary also so to arrange the locomotive stock as to obtain from each engine in steam a maximum train mileage. As far as it can be estimated from the return of traffic on the best managed lines, it would appear that from 70 to 80 miles per day is the greatest average distance run by engines hitherto; and this probably for only four days out of the week.

An engine, it has been considered, will consume 15 lbs. of coke for itself and $\frac{1}{5}$ lb. additional per ton weight of train, some allowance being made for the consumption in getting up the steam: the cost of locomotive power, including interest on locomotive stock, may therefore be assumed at 7*d.* + cost of 40 lbs. of coke = 10*d.* to 13*d.* per mile; and an average of the locomotive charges, estimated from the half-yearly returns of nineteen Companies for the last half of the year 1847, gives the cost per mile at 12·12*d.* On the York, Newcastle, and Berwick Railway, however, the present average consumption of coke is 26 lbs. per passenger train per mile run, or 10 lbs. for the engine and 2 lbs. additional, per mile, for each carriage: the goods trains vary in weight from 150 to 400 tons, and the average consumption of coke per train per mile, for goods engines, is 50 lbs. To encourage the engine-drivers to save coke, it is the custom on many lines to give them a premium for all the coke saved under an average. On the above-mentioned railway, the engine-drivers receive 1*s.* for each lb. saved under the average per fortnight, and the fire-men 4*d.*

Wear and Tear of Carriages.—The charges for wear and tear of carriages, and interest on the capital invested in them, may be assumed at

1*d.* per mile run for first-class carriages,
$\frac{1}{2}$ „ second-class ditto,
$\frac{1}{4}$ „ third-class ditto, and waggons and trucks.

It has been estimated that on British railways the average daily mileage of 1st-class carriages, capable of containing 18 passengers, is 59 miles, and that they convey on an average 7 passengers;—of 2nd-class carriages, capable of containing 25 passengers, it is 45 miles, and they convey on an average 13 passengers; and of 3rd-class carriages the daily average mileage is 38 miles; they are capable of containing 32 passengers, and carry on an average 21,—whilst the average daily mileage of passenger carriages on French and Belgian lines is 39 miles. The average daily mileage of the goods-carrying stock on British lines is 27 miles, and the average load $2\frac{1}{2}$ tons; whilst that on Continental railways is $16\frac{1}{4}$ miles. The comparatively small amount of daily mileage of goods-waggons is due to the time consumed in loading and unloading, and waiting for a complete train. It is stated that on the London and North-Western Railway the number of vehicles in a passenger train averages 7, of which 4 are passenger carriages, the gross load being 70 tons; and that the average weights of goods trains are 154 tons, or 120 tons net load, *i. e.* they contain about 24 waggons.

It is considered that the periodical repairs which the working stock of a railway undergoes keep it up to its effective value to the Company, and that hence no reserve fund is requisite for replacing it.

The total cost of working railway trains has been stated to be from 3*s.* to 5*s.* per mile, including everything; and the following classification of the items on the London and Birmingham Railway is given in the Appendix to a Report to the House of Lords on Railway Communication between London and Birmingham, published in 1848:

	s.	*d.*
Maintenance of way	0	$5\frac{1}{4}$
Locomotive power	1	0
Police	0	2
Coaching and merchandise	0	$7\frac{3}{4}$
Coach and waggon repairs	0	$2\frac{1}{2}$
Depreciation of stock	0	4
Mileage duty	0	$5\frac{1}{2}$
Rates and taxes	0	3
General charges	0	2
Total	3	8

Goods trains cost 8*d.* per train per mile additional.

The following is an approximate analysis of the proportions between the several expenses of working and maintenance, obtained from five of the principal railways in this country, viz.

Direction and management	6·8
Maintenance of way and works	15·8
Locomotive power	35·1
Carrying department	38·6
Office, and miscellaneous	3·7
	100·0

In some small lines, when ready money for the purchase of stock has not been easily procurable, agreements have been entered into, contracting for the working of the line, and it is under such circumstances alone that the system appears advisable.

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Locomotive power	35·1
Carrying department	38·6
Office, and miscellaneous	3·7
	100·0

In some small lines, when ready money for the purchase of stock has not been easily procurable, agreements have been entered into, contracting for the working of the line, and it is under such circumstances alone that the system appears advisable.

The North Western Railway Company is one that has adopted this plan, and the North Staffordshire Railway Company another. In the first case, the contractor is bound to run trains capable of conveying 132 passengers each, at such times as the Company desire, at 1*s.* per train per mile, the contractor finding the engines, carriages, &c., and 6 per cent. additional being allowed him for shunting. The goods traffic the contractor conveys at 1*s.* 8*d.* per ton per mile, the waggons being found by the Company. The following Table shews the rates to be paid by the North Staffordshire Railway Company to the contractor, who finds all the locomotive stock, plant, &c.

Locomotive power per mile.				Carriages, &c. per mile.								
Miles per hour.												
30	40	18	12									
Passengers.		Goods or minerals weighing 120 tons.		1st Class.	Composite.	2nd Class.	3rd Class.	Horse-boxes.	Brake vans.	Carriage trucks, vans, &c.	Empty vans.	
d. 13		*d.* $14\frac{1}{2}$	*d.* $13\frac{1}{2}$	*d.* $\frac{7}{8}$	*d.* $\frac{3}{4}$	*d.* $\frac{5}{8}$	*d.* $\frac{1}{2}$	*d.* $\frac{5}{9}$	*d.* $\frac{3}{8}$	*d.* $\frac{1}{2}$	*d.* $\frac{1}{4}$	

The contractor is subject to certain charges for use of stationary plant, &c.

Cost of Working.—The following statement of the cost of working and maintenance for the half-year ending June, 1850, on the London, Brighton, and South Coast Railway, may prove interesting:

Maintenance of way per mile run	6·16*d.*
Maintenance of way per mile of railway	£93.
Locomotive power per train per mile	$10\frac{1}{2}$*d.*
Coach and waggon repairs per train per mile	$4\frac{1}{2}$*d.*
Coaching per cent. on coaching receipts	8
Goods charges per cent. on goods receipts	$13\frac{1}{2}$
General charges per cent. on gross receipts	$2\frac{6}{10}$
Taxation per cent. on gross receipts	$7\frac{1}{2}$
Average receipts per train per mile, exclusive of cartage	7*s.* 7*d.*
Total expenditure per train per mile	3*s.* 5*d.*
Total expenditure per cent. on gross receipts	$43\frac{3}{10}$.

It would appear also, from an average obtained from the returns of the principal Railway Companies, that 43 per cent. is about the proportion of the expenditure to the gross receipts in this country, whilst the average return on the capital has been stated to be 3·4 per cent. From a return of railways in Prussia, Austria, Saxony, and Bavaria, it would appear that the expenses of working, in 1848, were 58·46 per cent. of the gross receipts, and the return on the capital expended 3·19 per cent. From the half-yearly return of traffic on railways published by Government, it appears that the proportion of goods to passenger traffic is continually on the increase.

It may be as well to mention in this place, that the rapidity of transport between two places by train on a railway will depend more upon the number of intermediate stoppages than upon the speed maintained by the train whilst in motion; since each stoppage may be considered to consume five minutes, viz. $1\frac{1}{2}$ minute for the train to come to rest, $1\frac{1}{2}$ minute to start, and 2 minutes to remain at the station.

Fares.—The fares which the public have to pay on railways may be divided into two parts; the first being what a Company constructing a line would charge as a toll upon the passengers and merchandise using it, and would be made up of a sum for

interest on the capital expended in the construction of the line, the cost of maintenance, and of police. The second is, what a Company working the line would charge, and is made up of the actual cost of conveyance, the interest on the working stock, and the charges for superintendents, clerks, porters, &c. The proprietors of a railway will always be able to carry at a lower rate than any one else upon their own line under a fixed system of tolls, because any receipts beyond the mere cost of conveyance and maintenance would be a profit; whilst other persons using the line would have to pay, under the head of toll, a fixed interest on the capital employed in the construction.

In fixing the sums to be charged, therefore, it is necessary to obtain an approximate estimate of the number of passengers, and the quantities of merchandise to be expected on a railway,—assuming, in the first case, a certain number of trains per day for the cost of locomotive power;—and in estimating the price per ton to be charged for merchandise, the gross amount would be divided by what would constitute an average load,—the classes of goods, cattle, &c. being obtained from an assumed bulk per ton.

Traffic.—The first point to be considered in estimating the probable traffic on a railway is the size of the district which will employ the line as a means of conveyance. In a wealthy and a mercantile community, where time is of more value than money, the most rapid mode of conveyance will be preferred; whilst in a poor country, and for the carriage of goods, the railway will only be adopted when its use will insure diminished expense; or, in other words, the limit for the probable contingent traffic of a railway will be the point at which the land carriage to the line, together with the conveyance upon it, can be effected in less time or at less expense than the other available land carriage for the whole distance. It must, however, be borne in mind that the land carriage to the line should be estimated along the main roads leading to the nearest station, and that for short distances the inconvenience of changing carriages, and the delay, will often more than counterbalance the advantages to be derived from using the line; and hence, for the full development of local traffic, rigid punctuality in the arrival and departure of trains is of more importance than appears to be generally understood.

In estimating the passenger traffic, it may be assumed that the intercourse between different places would vary as the product of the population, and according to some law of the distance, all other circumstances of population and rate or speed of conveyance being the same. The law of the distance would of course depend upon the habits, pursuits, and wealth of the population; and a fair value for each description of population could only be obtained from a number of general averages. It is to be regretted that Railway Companies do not publish, in their half-yearly returns of traffic, the numbers of passengers between the several stations on their lines. The only returns of the sort which have been published were by the South Eastern Company, for the year 1845, in a Report to a Committee of the House of Commons on Railway Acts Enactments, in 1846; and although that line is almost the worst which could have been selected, both from being the main road between London and the Continent, and because the agricultural population through which it passes is not concentrated about the stations along the line,—and therefore the results cannot be relied on as correct co-efficients for the distances,—yet they will exhibit the effect which distance has in rapidly diminishing the per-centage of the population which travels. The average co-efficients for an annual traffic which have been obtained are as follows:

For a distance of about 6 miles, $\frac{1}{800}$
" " 10 " $\frac{1}{2500}$
" " 15 " $\frac{1}{4000}$

For a distance of about 20 miles, $\frac{1}{12000}$
" " 30 " $\frac{1}{18000}$
" " 40 " $\frac{1}{50000}$
" " 50 " $\frac{1}{70000}$
" " 60 " $\frac{1}{90000}$

In framing estimates based upon similar data, it is necessary to recollect, that whilst towns which are situated on the line should have their population reckoned at the full value, those towns situated at a distance from the line, and agricultural districts, may be considered as towns of a proportionately smaller amount of population concentrated at the stations.

The fact to be inferred from the above, viz. that the great mass of passengers consists of those who travel short distances, is further confirmed from the result of traffic returns in Great Britain for the last six months of 1848, shewn in the first column of the following Table; and the result given is in accordance also with what might be presupposed, viz. that the poorer classes would avail themselves of railways for short distances more than those classes who possess other means of locomotion. From the results stated in the second and third columns, it would appear that the inferior classes of passengers form the chief source of railway business.

	Average distance travelled by each passenger.	Per-centage of each class booked on the number.	Per-centage of each class on miles travelled.
1st Class .	27·0	19·3	11·8
2nd Class	16·5	38·5	38·6
3rd Class .	14·0	42·2	49·6
Average .	16·5	Total 100·0	Total 100·0

Where there are no competing facilities on either side of a railway, and no natural barriers to impede the traffic, it may be assumed that the probable amount of merchandise which would be conveyed upon a railway would be the whole surplus produce of the district through which the line would pass, together with the imports which would be required for the consumption of the population of the district, as well as part of the surplus produce, and of the imports for consumption of such other parts of the country as would find it advantageous to use the line as a medium of communication. There are no official documents from which, for this country, the transmission of different descriptions of produce from one part of the country to another can be judged of; and it would be beyond the limits of the present article to describe the modes which have been adopted to obtain it.

It may, however, be curious to observe, that it has been estimated that the average distance travelled on railways for each unit booked is, for

Merchandise, tons, ...	$22\frac{1}{2}$ miles.
Cattle, number, ...	$30\frac{1}{3}$ "
Sheep, do.	$32\frac{2}{3}$ "
Pigs and Calves, do. . . .	$55\frac{2}{3}$ "

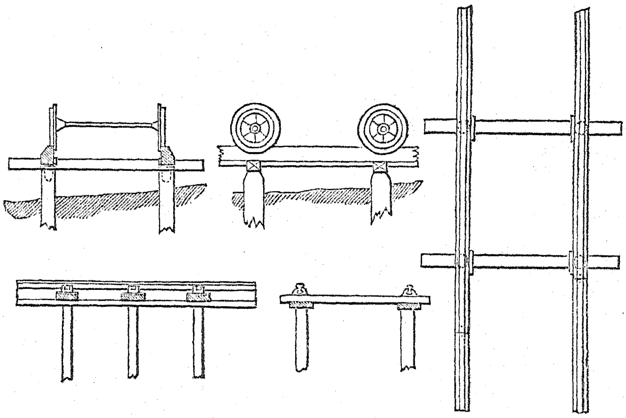
and that whilst in a period of six years and a half the passenger traffic on railways only increased 28 per cent., the goods traffic was augmented 282 per cent.

The principal points to be attended to in working a railway are to obtain a maximum daily mileage from the engines, combined with a maximum effective load in the trains; and since the terminal expenses for goods traffic are comparatively heavy,

it should be remembered that the greater the distance the goods are conveyed, the smaller will be the proportionate expense.

American Railways.—Having now stated the general principles upon which railways are constructed and worked, more particularly in this country, it is proposed to add a few remarks on the cheaper arrangements which have been adopted in America. In that country railways have been constructed at an expense of from £8000 to £9000 per mile. The country they pass through is generally level, requiring low embankments and shallow cuttings. The bridges are of timber from the adjacent forest (occasionally with stone abutments and piers), and frequently the stations, offices, and other buildings are also of timber. From the comparatively limited amount of traffic conveyed upon them, a single line, with sidings at intervals, frequently suffices at first; and should a double line be required, it can be added from the profits. The lightness of the traffic and the moderate speed, viz. 14 or 15 miles per hour, have permitted a more economical roadway than that in use in this country: the curves are frequently of 7 chains radius,—curves of 15 chains radius are usual; and gradients of 1 in 75 are numerous. In some instances, under peculiar circumstances, and where timber was abundant, pile lines, as shewn in the accompanying sketch, have been constructed; where high above the ground, diagonal braces have to be introduced so as to form trestles: instances are, however, stated to

Fig. 18.



have occurred where these viaducts have warped, and let the engine slip down between the rails. In consequence of the cheapness of wood and the high price of iron, light rails, laid on longitudinal bearers, are used, which are supported by cross bearers, 5 feet apart. When the traffic is light, the longitudinal timber of hard wood sometimes forms the rail, having its edge protected from splitting by a plate of iron let into it and spiked down, $2\frac{1}{2}$ in. broad and $\frac{1}{2}$ in. deep. This plate, however, when so fixed, is liable to rise up at the end, and to *snag* the engine; and rails similar to those in this country, but with the sleepers at shorter intervals, to admit of a lighter rail, viz. from 25 to 30 lbs. per yard, are in general use. When increased traffic is anticipated, the earthworks, &c. are constructed for a double line.

The speed on these lines, stoppages included, is 14 or 15 miles per hour; and the fuel in ordinary use is wood (except in the coal districts, where coal is used), from its cheapness, and from the smoke not being objected to in a thinly-peopled

country. The carriages are only adapted to convey one class of passengers, except that a compartment is set apart for people of colour: they are of great length, with a passage down the middle, on each side of which are seats placed crosswise, and there are doors at either end. Each carriage accommodates from 60 to 80 passengers. To enable these carriages to move round curves, instead of resting directly on the axles, each end rests on a four-wheeled railway-truck, to which it is attached by a pivot. Railways are frequently carried to the centres of the towns, along the sides of the streets; the train for the latter part of the journey being drawn by horses. In the parts of the country exposed to snow, and where it is liable to fall to a great depth, it is considered advisable, in order to obviate as much as possible the probability of interruption from this cause, to keep the rail to the height of the average depth of the snow in the country. In order to clear lines from snow, snow-ploughs are used. In a double line the ploughshare lies over the inner rail, and throws the snow outwards,—first clearing one track and returning by the other; whilst for a single line the ploughshare travels along the centre of the track.

Railways have been constructed in America, as in this country, by joint-stock companies,—the State, however, reserving to itself considerable powers. But Companies are not exposed to the same preliminary difficulties that they are subjected to in this country and in France. The time for the completion of the works is limited under pain of forfeiture, and the traffic in shares before the Company is definitively formed is prohibited.

Comparative Cost of Railways.—The following prices have been given by the Statistical Society as the cost per mile of railways in the subjoined countries, to the end of 1848, viz.

Austria	£12,000	Belgium . . .	£16,200
Prussia	11,100	France	21,300
Rest of Germany .	11,200	Great Britain . .	27,000
Whole of Germany	11,300	United States .	8,200

The following are works which give information on the subject of this article, and of which some use has been made in its compilation, viz.

Railways, by Drysdale Dempsey, Esq. C.E.
Baker's Railway Engineering.
Haskoll's Assistant Engineer's Railway Guide.
Bidder's Tables.
Macneill's Tables.
Huntington's Tables.
Seguin, Chemins de Fer.
Belpaire, sur les Dépenses d'Exploitation.
Lardner's Railway Economy.
De Pambour on Locomotives.
Weale's Tredgold on the Steam Engine.
Report of Commissioners on Railway Communication in Ireland.
Gauge Commissioners' Report.
Reports of the Commissioners of Railways.
Report of Railway Commissioners on Railway Communication between London and Birmingham.

RECONNOITRING.*

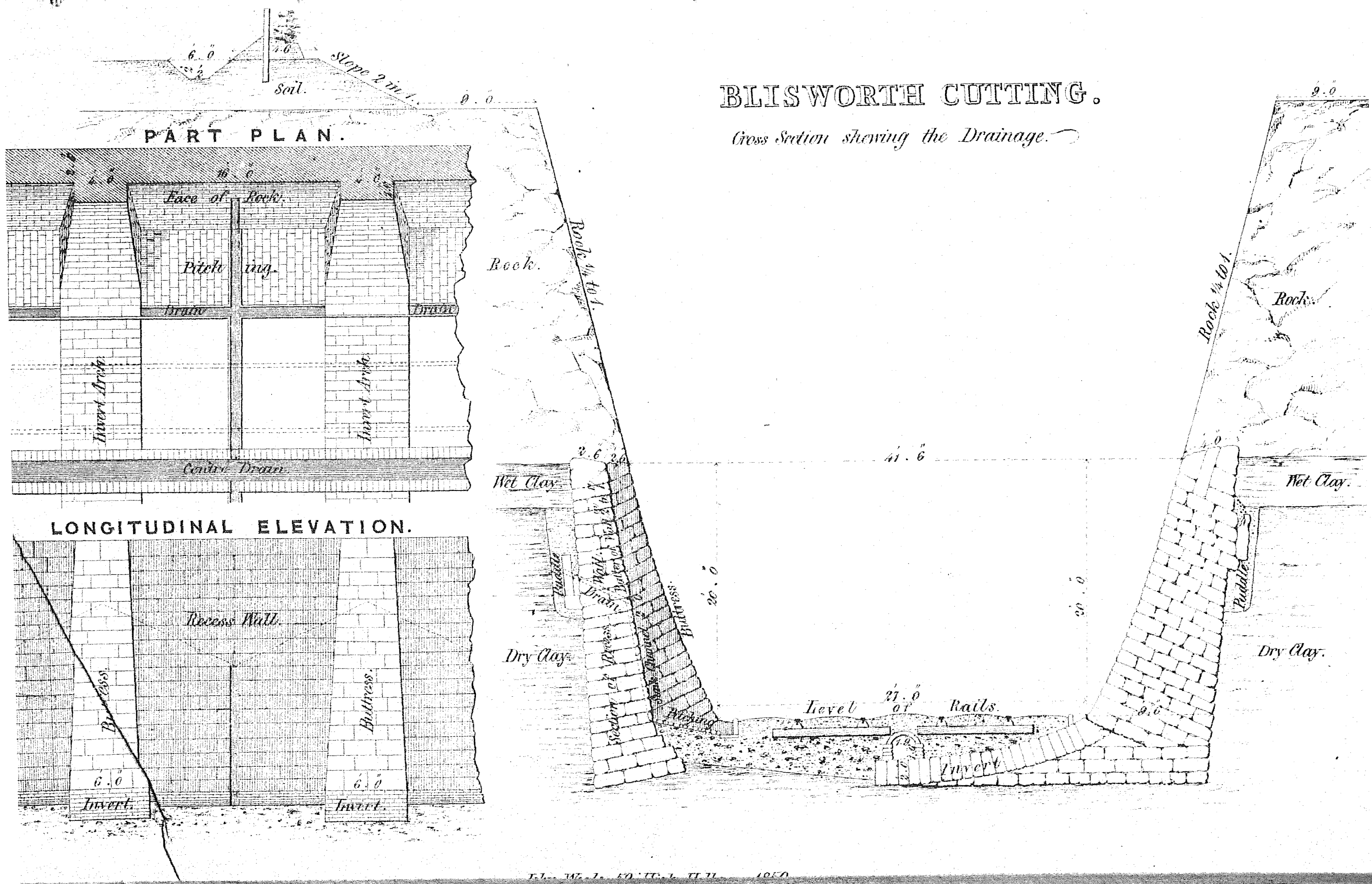
Military Reconnaissance of a Tract of Country.

This is usually effected, if in presence of an enemy, by a few mounted Officers, each protected by a small party of cavalry, and accompanied by some of the inhabi-

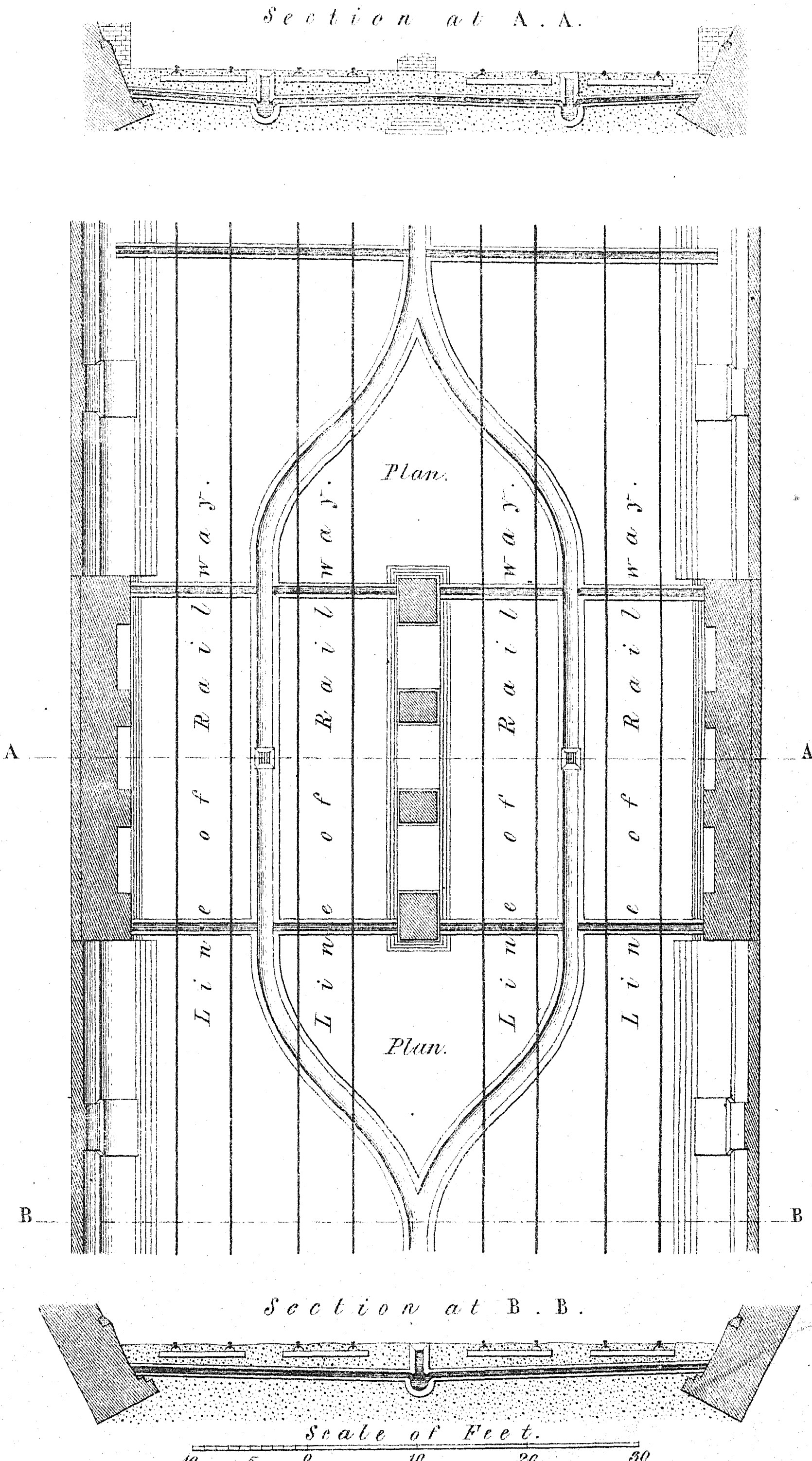
* By Captain Bainbrigge, R.E.

BLISWORTH CUTTING.

Cross Section shewing the Drainage.

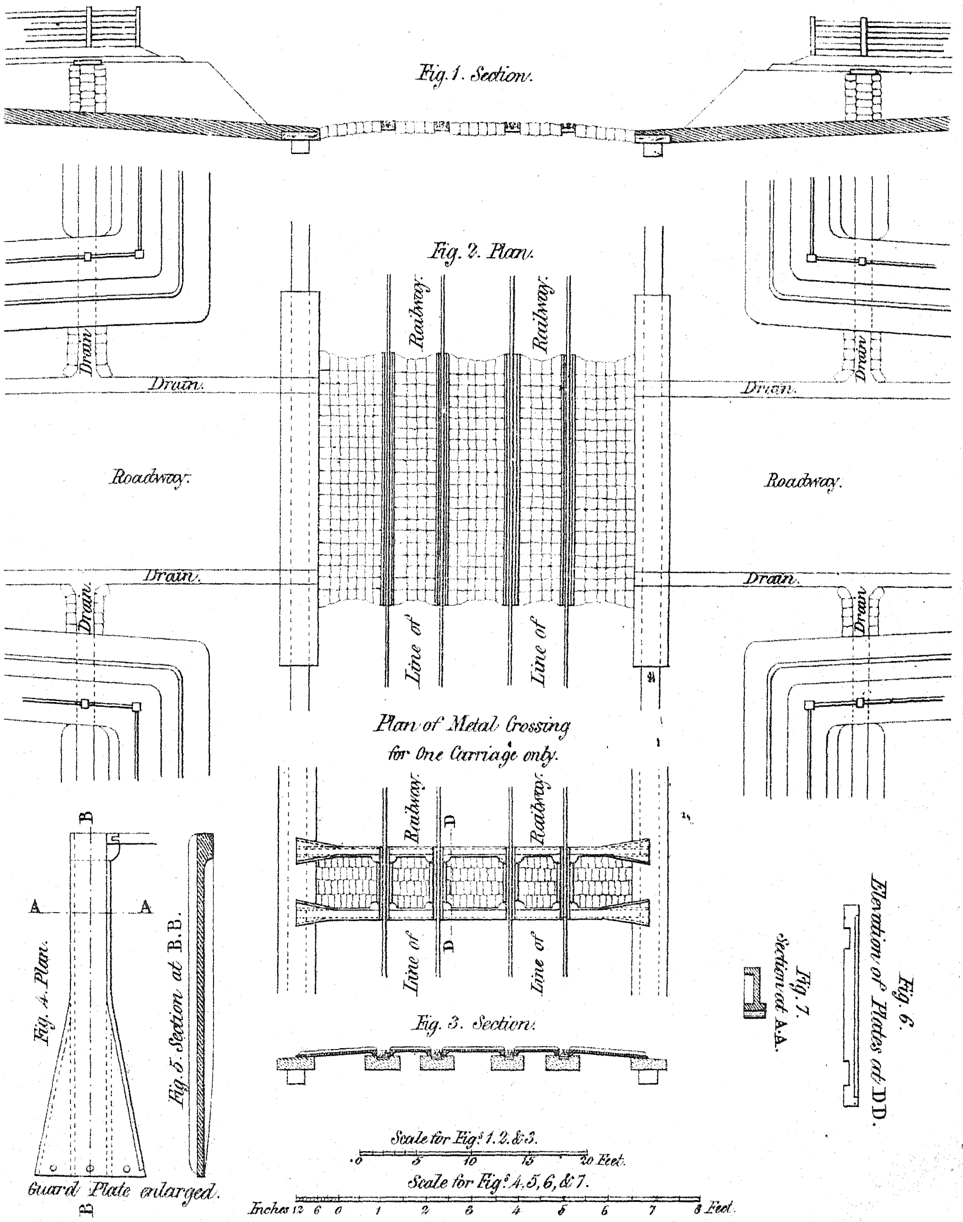


DRAINS UNDER BRIDGES.



PAVED CROSSING

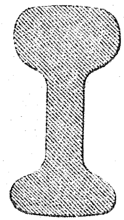
Admitting 2 Carriages to pass.



John Weale, 59, High Holborn. 1850.

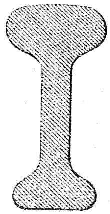
SECTIONS OF RAILS USED ON TRANSVERSE SLEEPERS.

85 lbs. Rail.



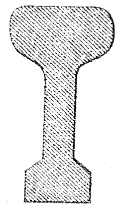
London & North Western, (Huddersfield & Manchester Line.)
Lancashire & Yorkshire, (West Riding Union, &c. (81 lbs.)
Edinburgh & Northern. (75 lbs.)
Cork & Bauden. (70 lbs.)
Lancashire & Yorkshire, (Burnley Branch. (82 lbs.)
Do. .... Do. ...... (Ardwick Branch. (82 lbs.)

66 lbs. Rail.



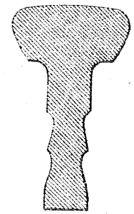
Norwich & Brandon.
Eastern Counties, (Enfield & Edmonton.)
Do. ...... Do. ... (Cambridge & St. Ives.)

60 & 65 lbs. Rail.



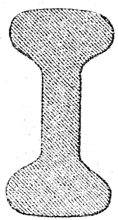
Gt. North of England, (Boroughbridge Br.)

65 lbs. Rail.



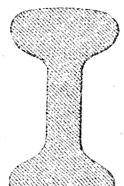
Manchester & Birmingham Railway.

80 lbs. Rail.



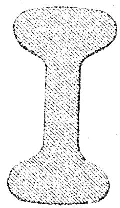
Windsor, Staines, & South Western Railway.
London & South Western, (Hampton Court Br.)
South Eastern, (North Kent Line.)
Reading, Guildford, & Reigate Railway.

75 lbs. Rail.



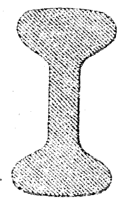
Caledonian Railway.
Eastern Union Railway.
Edinburgh & Bathgate Railway.
North British, (Harwich Branch.)
Scottish Central Railway.
Eastern Counties' Extension. (76 lbs.)
London & Brighton. (Eastbourn & Hailsham Br.)

71 lbs. Rail.



Liverpool, Ormskirk, & Preston. (74 lbs.)
North Staffordshire Railway. (72 lbs.)
Waterford & Limerick Railway. (71 lbs.)
Lancashire & Yorkshire, (Ardwick Branch. (68 lbs.)

65 lbs. Rail.

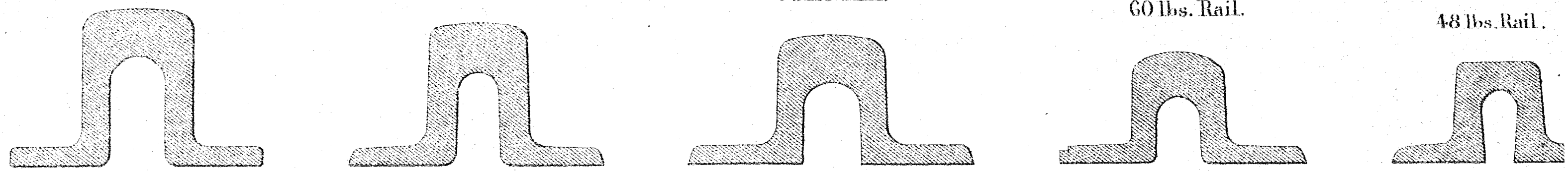


Aberdeen Railway.
Arbroath & Forfar Railway.

John Weale, 59, High Holborn, 1

SECTIONS OF RAILS USED ON LONGITUDINAL SLEEPERS.

85 lbs. Rail. — 81 lbs. Rail. — 75 lbs. Rail. — 60 lbs. Rail. — 48 lbs. Rail.



Liverpool & Bury Railway.

Belfast & Ballymena Railway.
London, Brighton, & South Coast Ry. (Hailsham & Eastbourne Br.)
Do. do. (Brighton, Lewes, & Hastings (80 lbs.)
Ulster Railway. (80 lbs.)

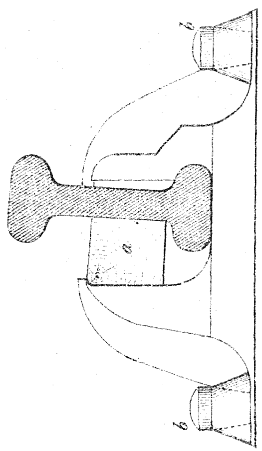
Lancashire & Yorkshire Railway, (Burnley Branch.)
Do. do. (Ardwick Branch.)
Manchester & Southport Railway.

South Devon Railway.

Cork & Bandon R.

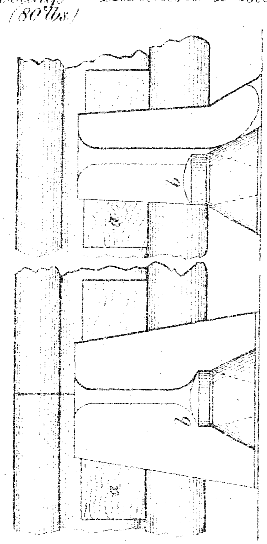
Shewing Ransom & May's compressed Oak Keys.

SECTION.



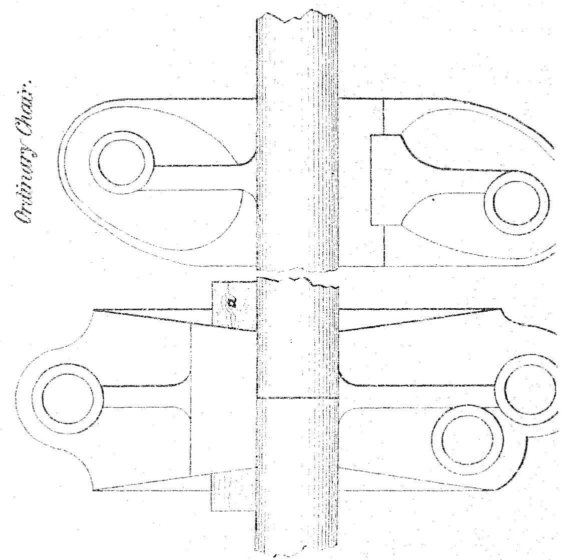
ELEVATION.

Ordinary Chair. — *Joint Chair.*

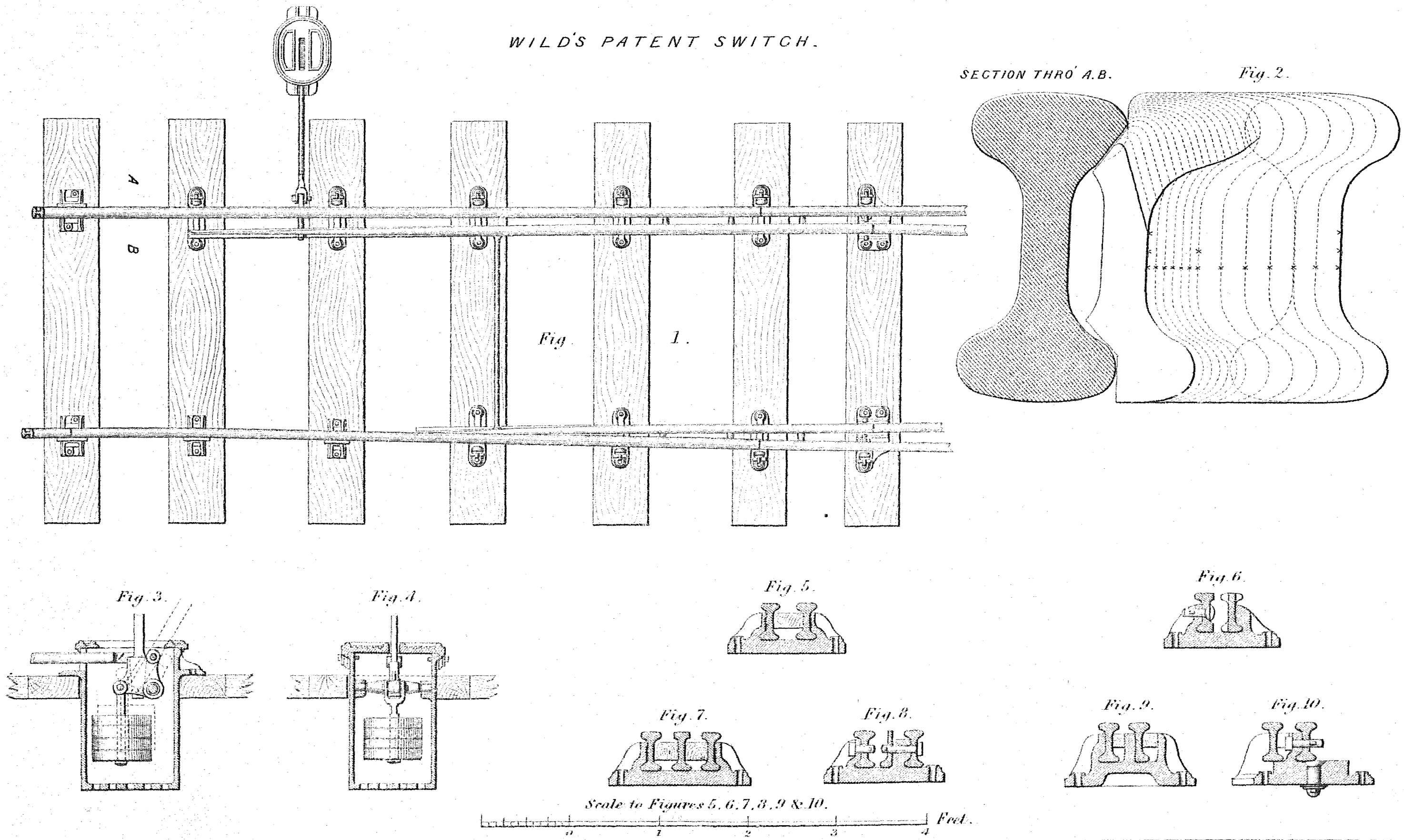


PLAN.

Ordinary Chair. — *Joint Chair.*

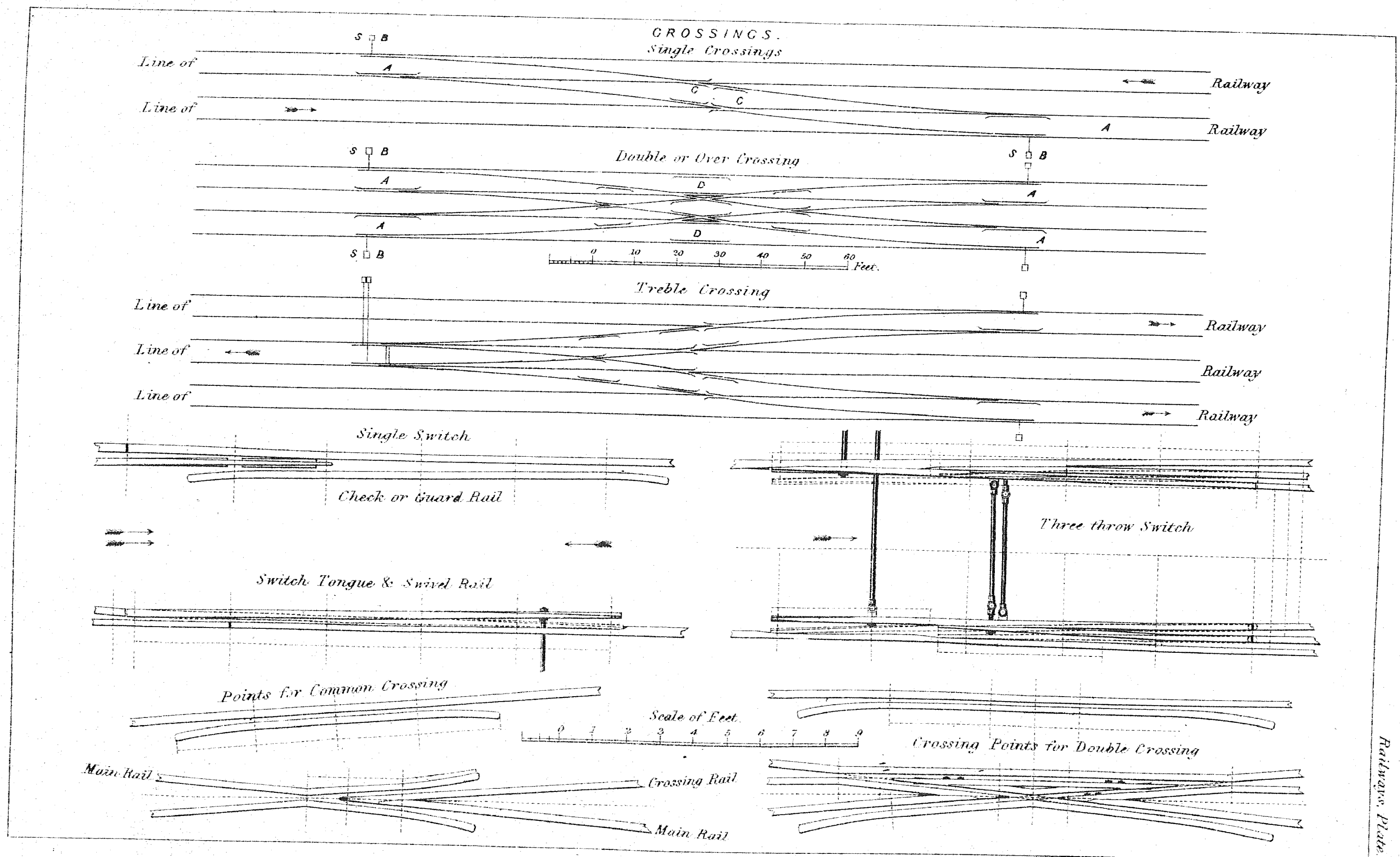


John Weale, 59, High Holborn. 1850.



W. A. Beever, Sc.

London, John Weale, 1851.



London: J. [illegible] Weale. 1850.

W.A. Beever Sc.

DUNN'S TURNTABLE

Fig. 1.

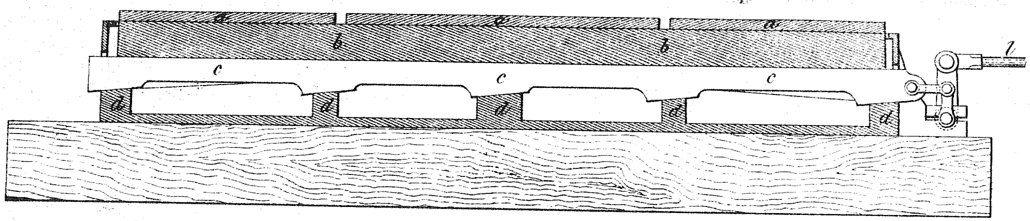


Fig. 2.

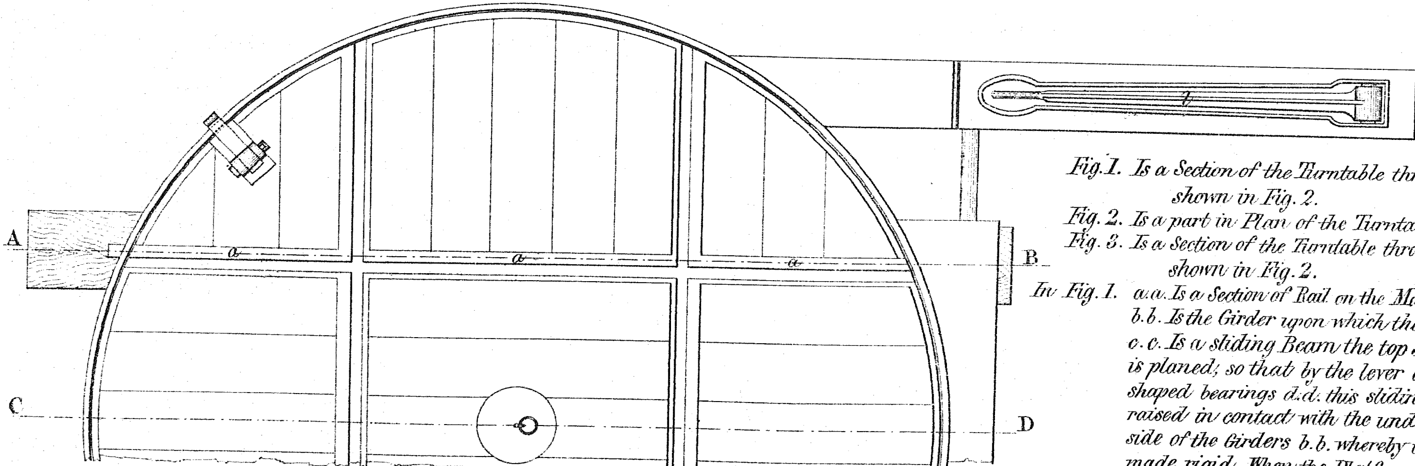


Fig. 3.

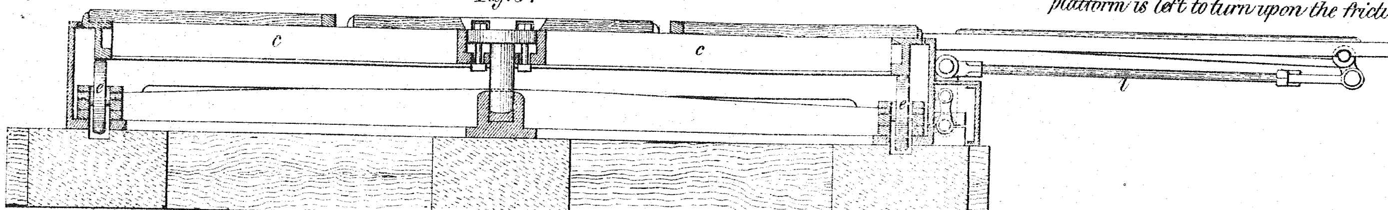


Fig. 1. Is a Section of the Turntable through the line A
shown in Fig. 2.
Fig. 2. Is a part in Plan of the Turntable top.
Fig. 3. Is a Section of the Turntable through the line CD
shown in Fig. 2.

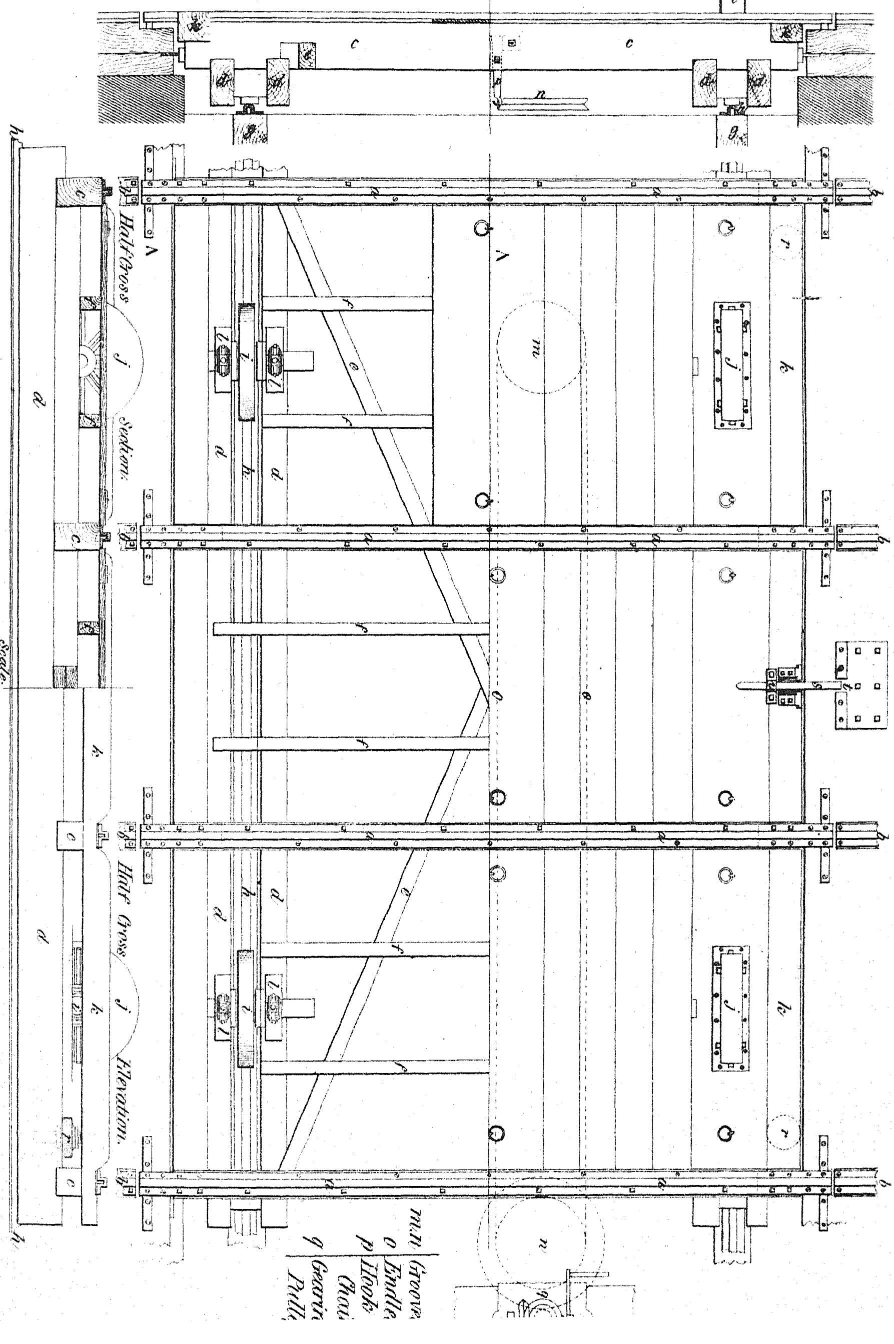
In Fig. 1. a.a. Is a Section of Rail on the Main Line of Way.
b.b. Is the Girder upon which the Rail is fixed.
c.c. Is a sliding Beam the top surface of which
is planed; so that by the lever l. and the wedge
shaped bearings d.d. this sliding beam may be
raised in contact with the under and planed
side of the Girders b.b. whereby the Platform is
made rigid. When the Platform is required to be
turned the sliding Beam is lowered by the lever l. and th
platform is left to turn upon the friction pulleys e.e. two
which are shown
Fig

John Weale, 59, High Holborn. 1850.

DRAWING OF PLATFORM,

Used occasionally instead of Turntable to transfer a Carriage from one Line of Rails to another.

Half Longitudinal Section. ——————— *Half Longitudinal Elevation.*



GOODS STATION.

Fig. 1.
Elevation on D.C.

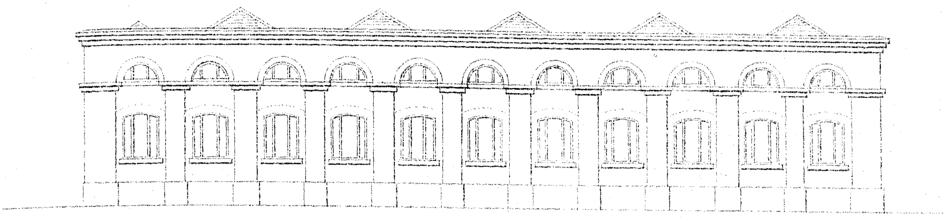


Fig. 2.
Elevation on A.B.

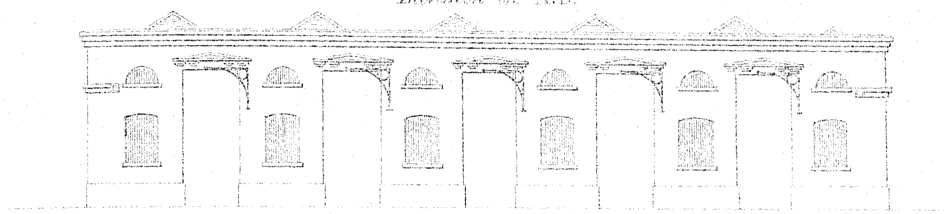


Fig. 3.
Ground Plan.

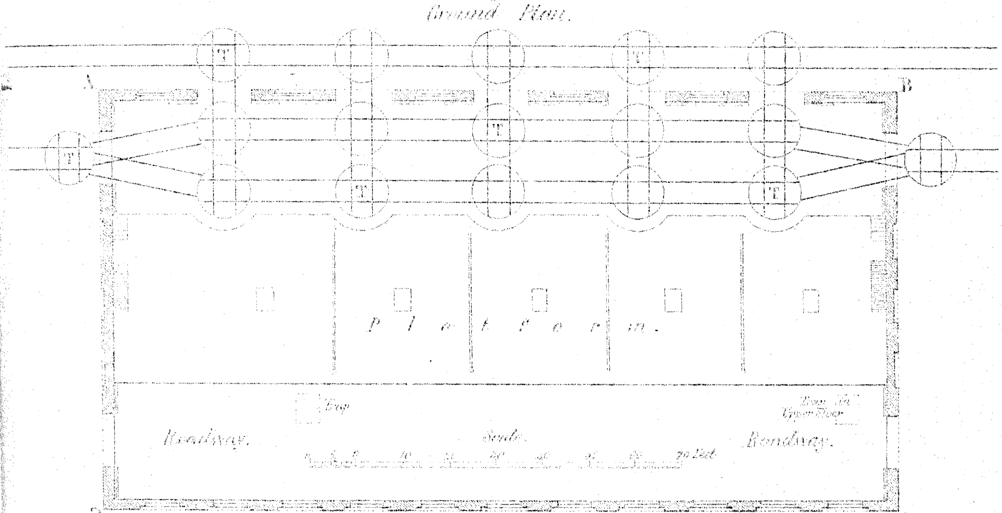


Fig. 4.
Transverse Section.

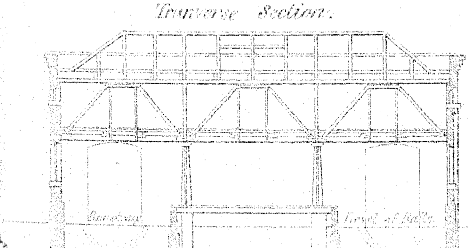
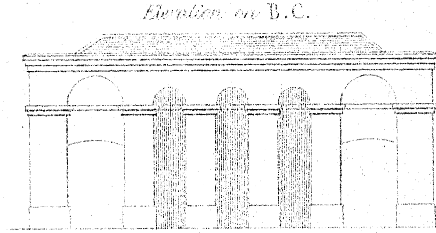
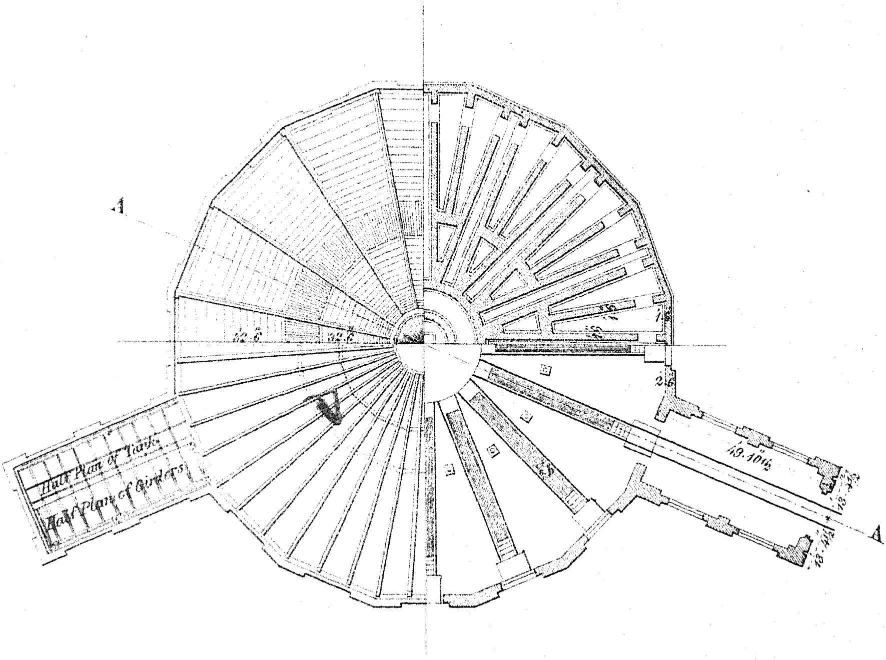


Fig. 5.
Elevation on B.C.

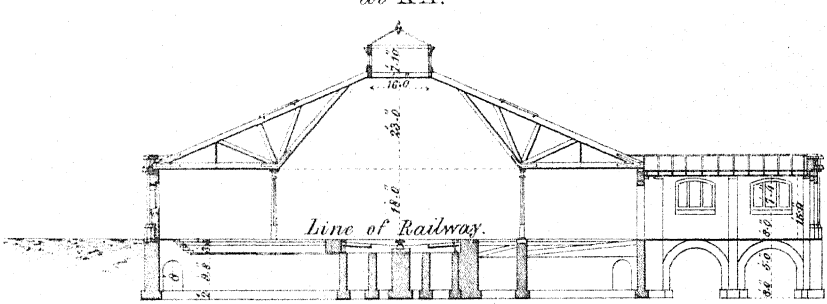


ENGINE HOUSE.

Plan.



Section at AA.



Scale of Feet.

0 5 10 20 30 40 50 60 70 80

John Weale, 59. High Holborn. 1850.

ELEVATION.

Fig. 3.

GROUND PLAN.

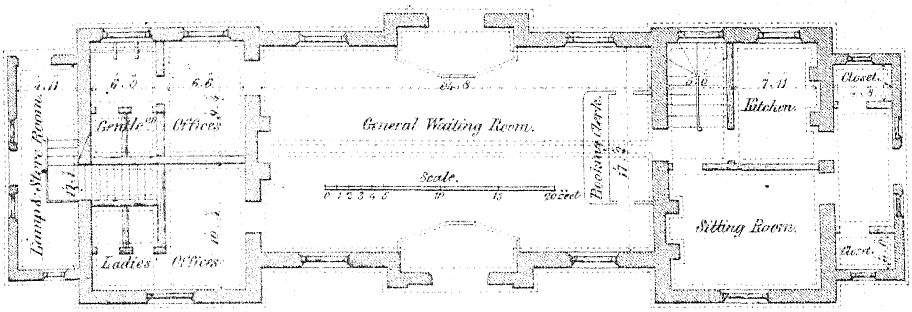


Fig. 4.

SECTION.

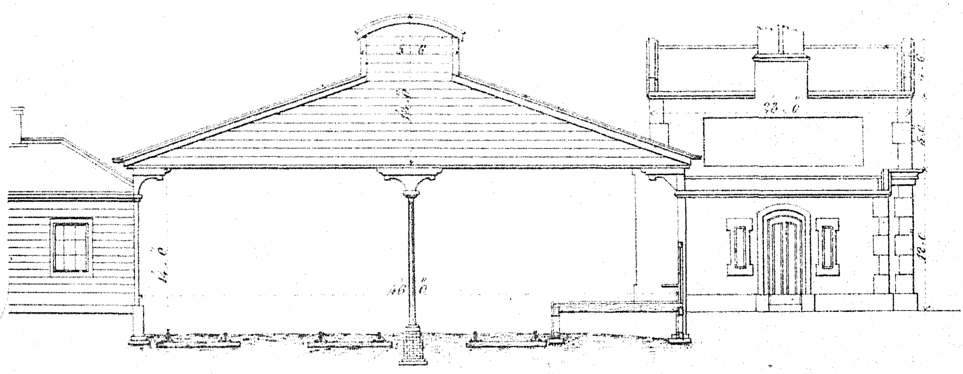
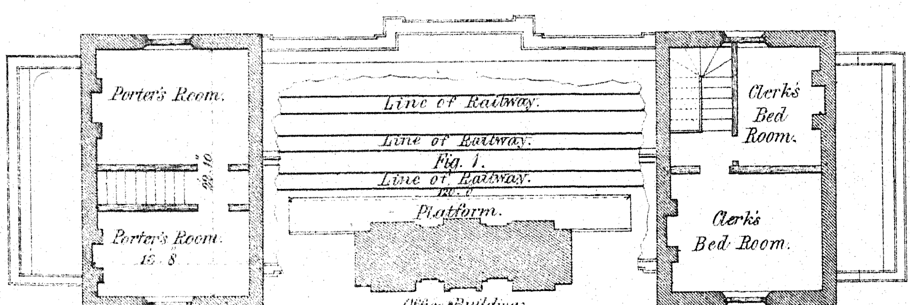


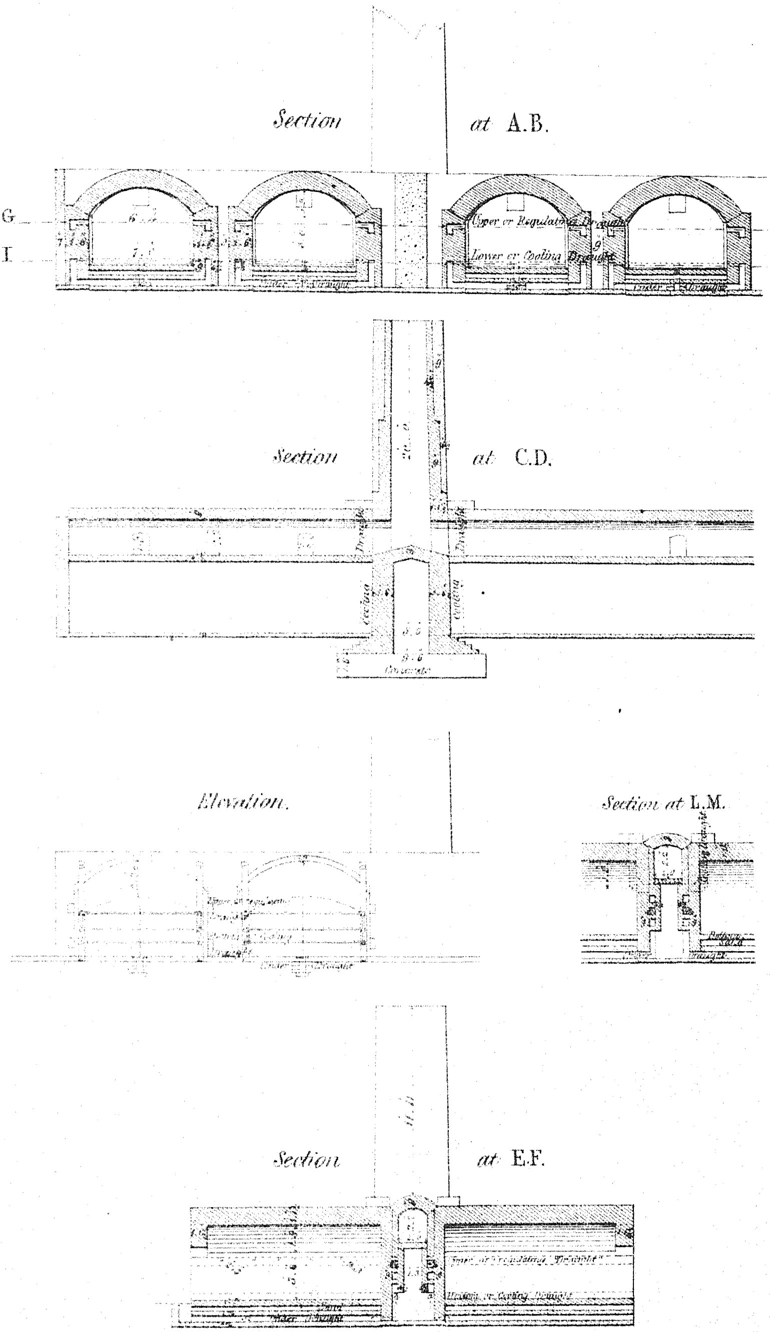
Fig. 6.



Office Buildings.
Scale 64 Feet to 1 Inch.

John Weale, 59, High Holborn. 1850

D.& E.R. COKE OVENS.



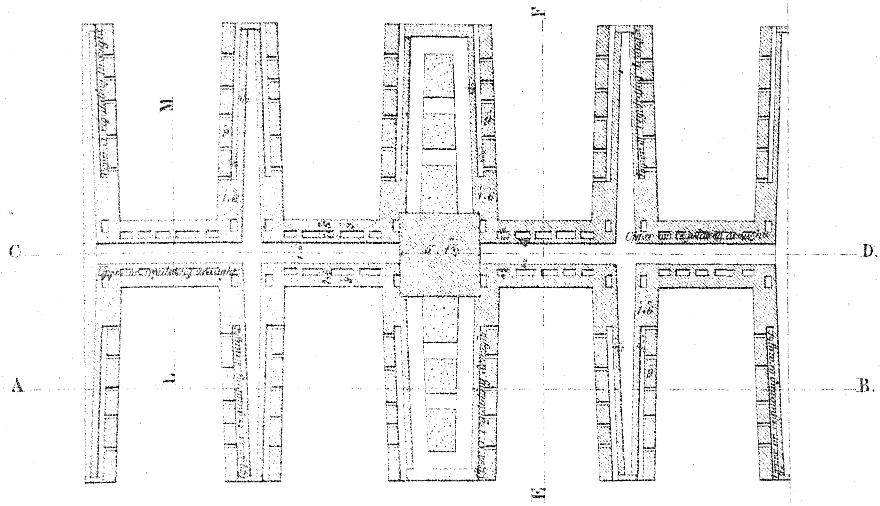
g A 6 inch Flue brought up from the bottom through the solid masonry

Scale.

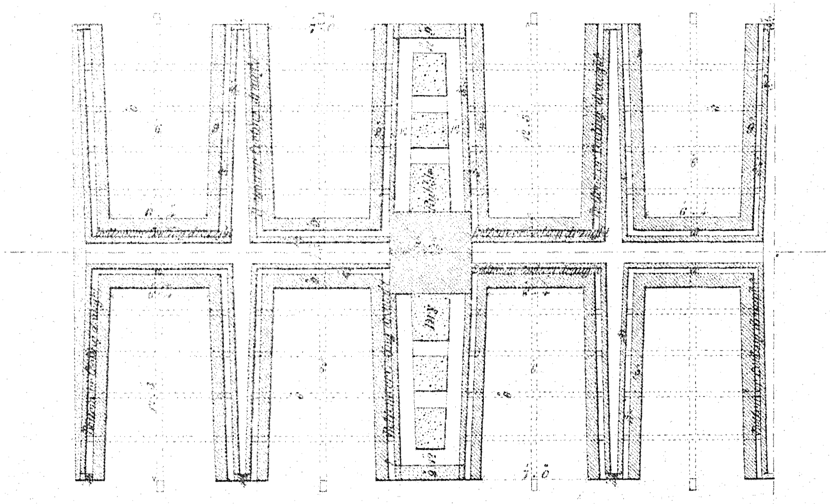
Inches 12 10 5 0 10 20 Feet

B. & E. R. COKE OVENS.

Plan at G.H.



Plan at I.K.



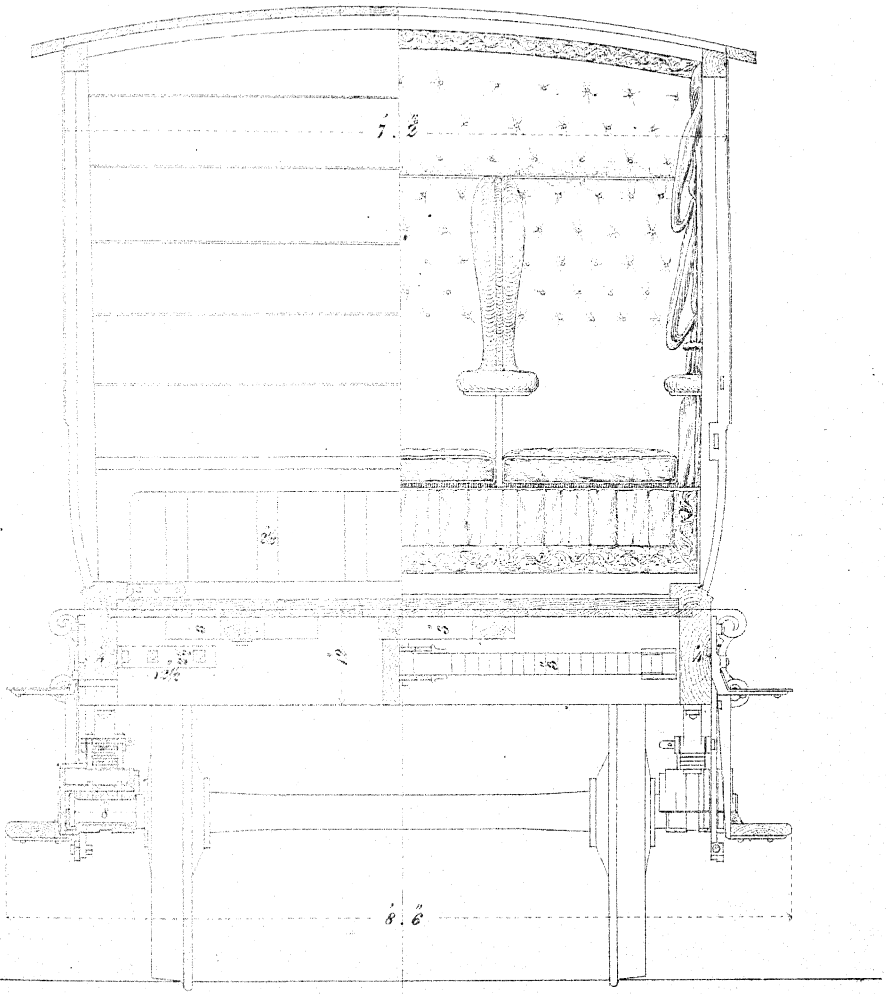
Scale.

Inches 12 10 5 0 10 20 Feet

John Weale, 59, High Holborn, 1850.

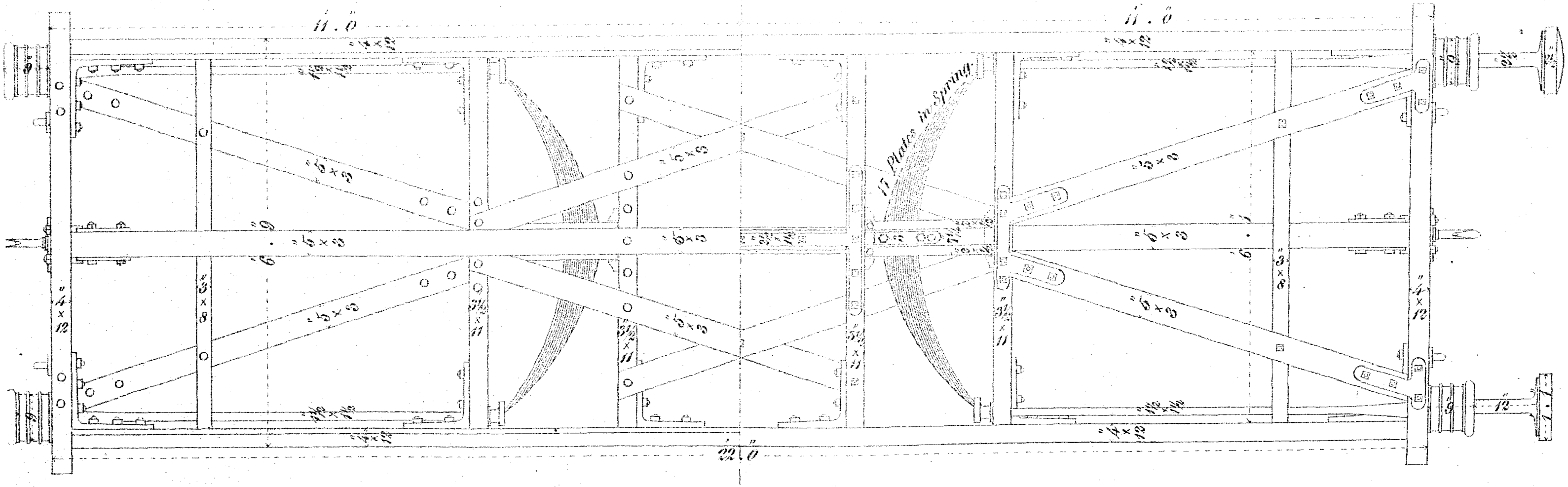
FIRST CLASS COMPOSITE CARRIAGE.

HALF TRANSVERSE SECTIONS.



FIRST CLASS COMPOSITE CARRIAGE.

HALF PLAN OF FRAMING. HALF PLAN OF FRAMING INVERTED.

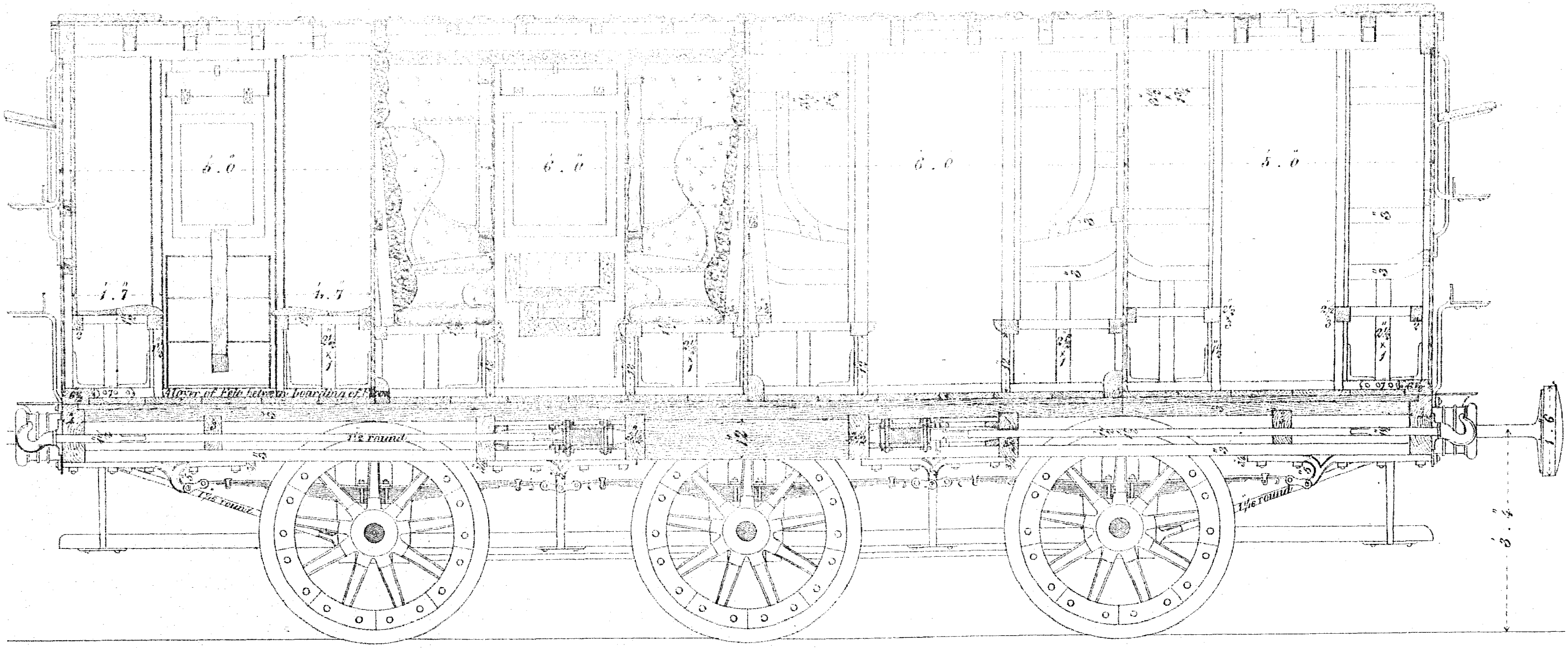


John Weale, 59, High Holborn. 1850.

C.F. Cheffins lithog.

FIRST CLASS COMPOSITE CARRIAGE.

HALF LONGITUDINAL SECTIONS.

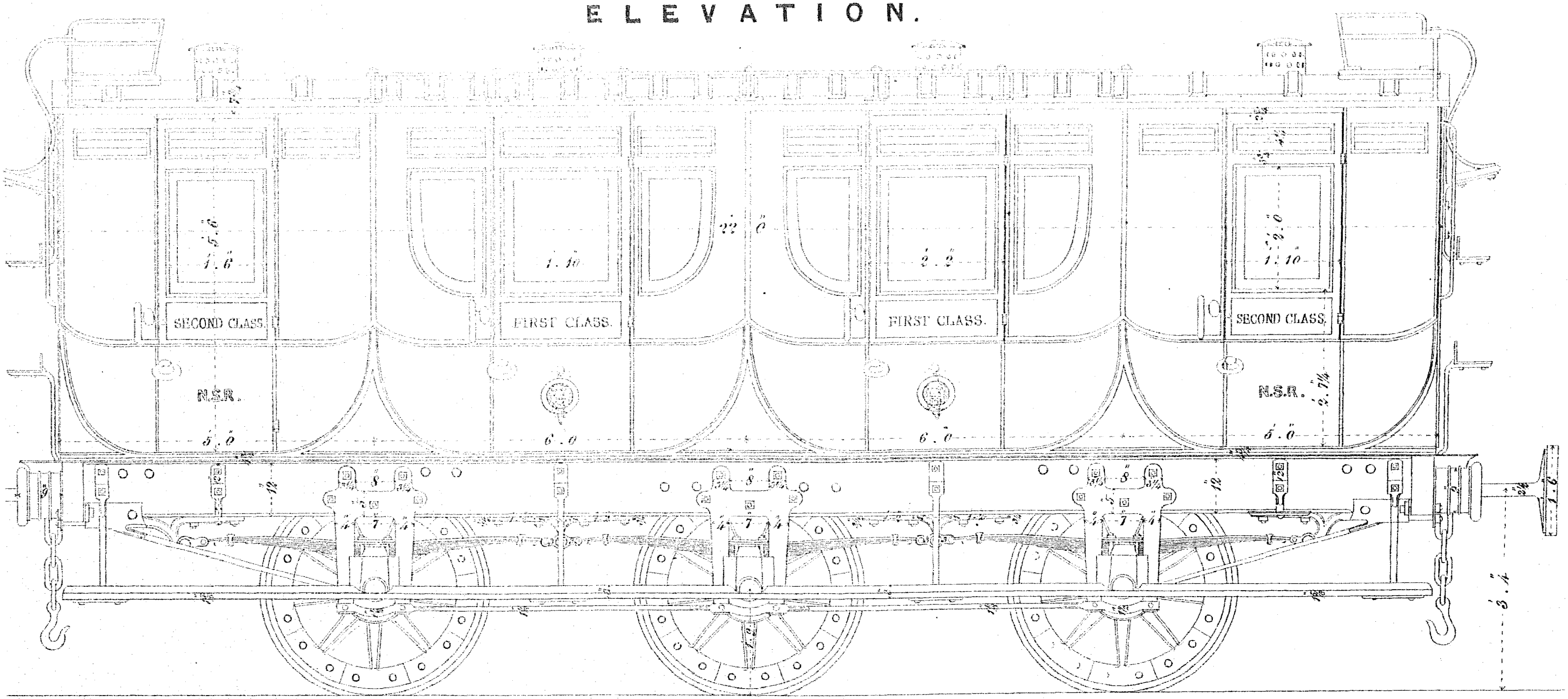


John Weale, 59, High Holborn: 1850.

C.F. Cheffins lithog.

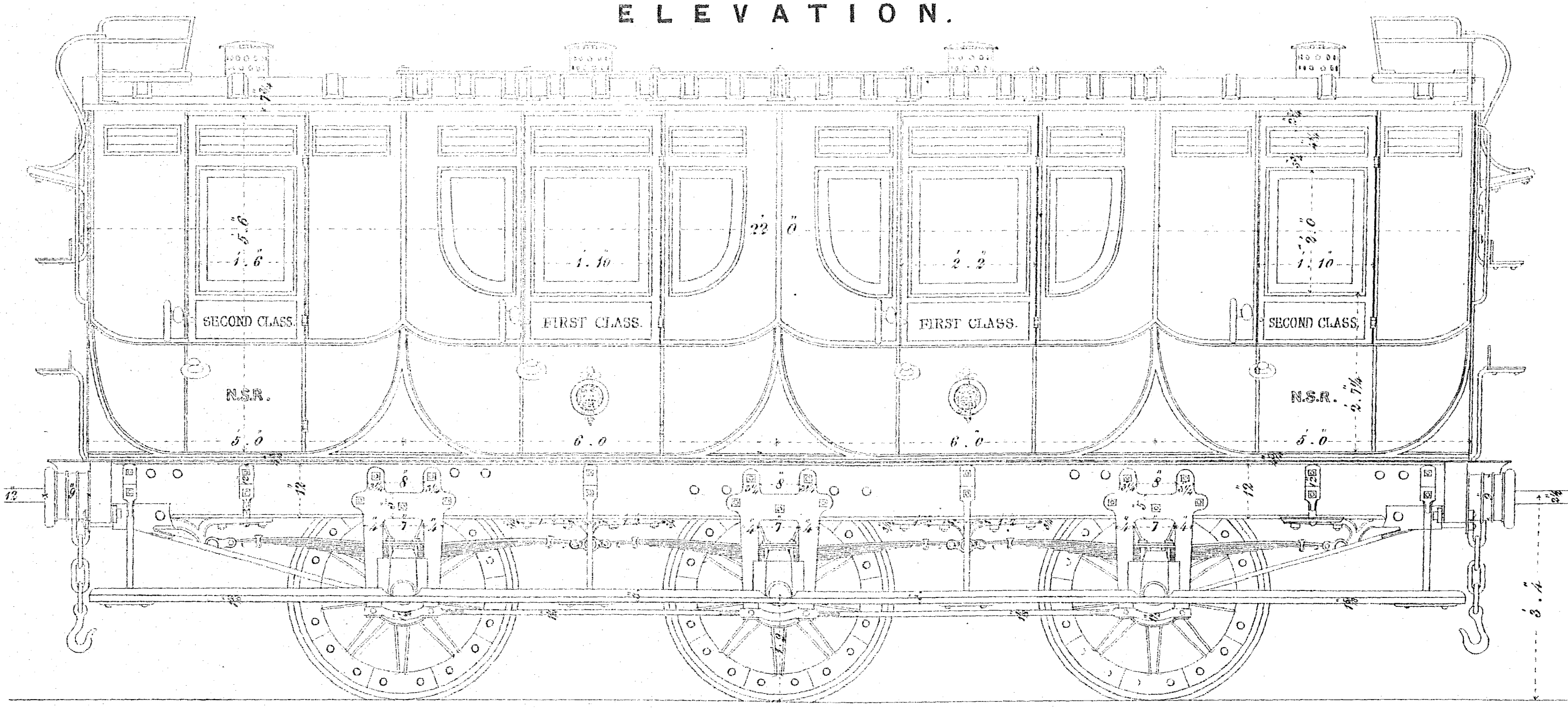
FIRST CLASS COMPOSITE CARRIAGE.

ELEVATION.



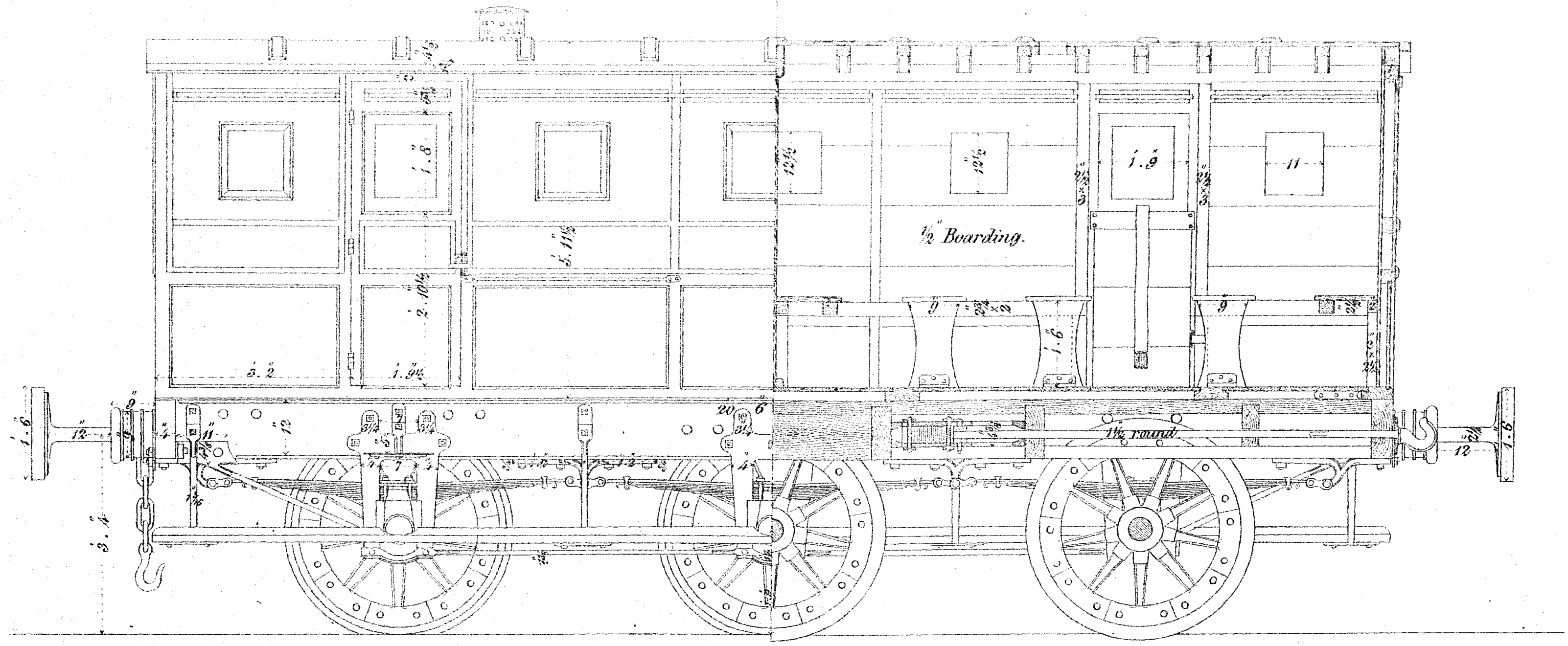
FIRST CLASS COMPOSITE CARRIAGE.

ELEVATION.



THIRD CLASS CARRIAGE.

HALF ELEVATION. HALF LONGITUDINAL SECTION.

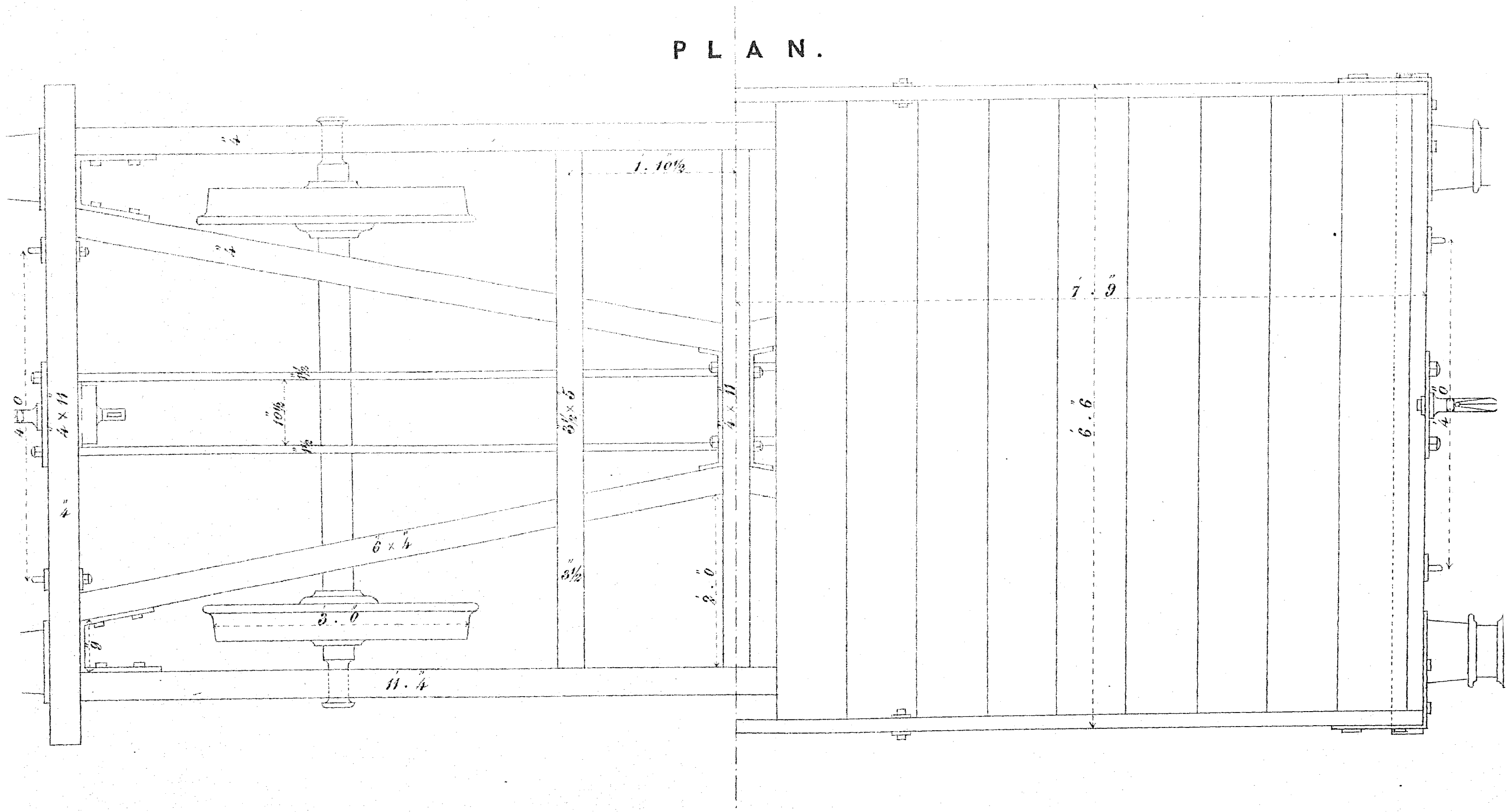


John Weale, 59, High Holborn. 1850.

C.F. Cheffins lithog.

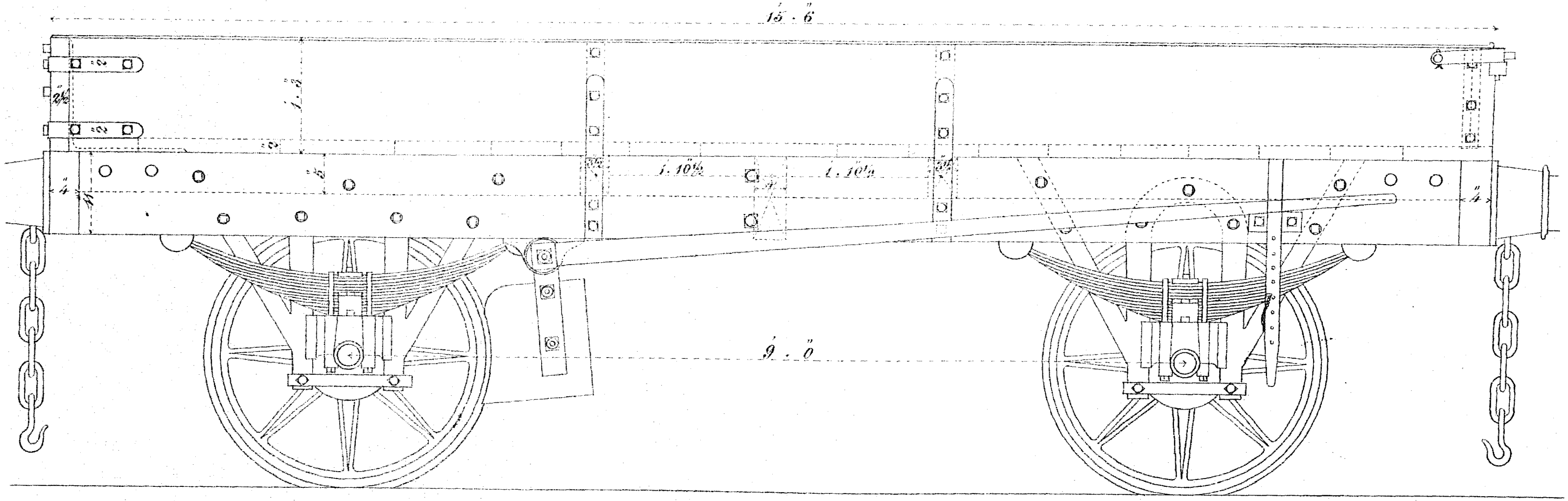
FRAMING OF LOW SIDED GOODS WAGON WITHOUT SPRING BUFFER.

PLAN.



LOW SIDED GOODS WAGON WITHOUT SPRING BUFFER.

ELEVATION.

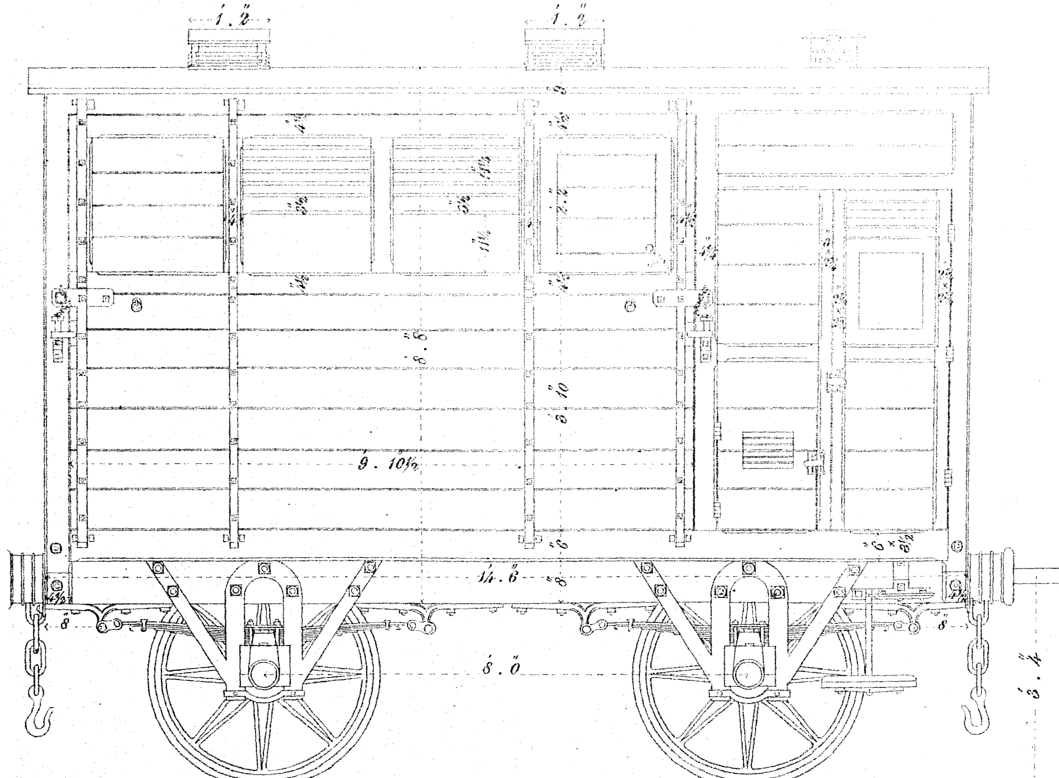


John Weale, 59, High Holborn. 1850.

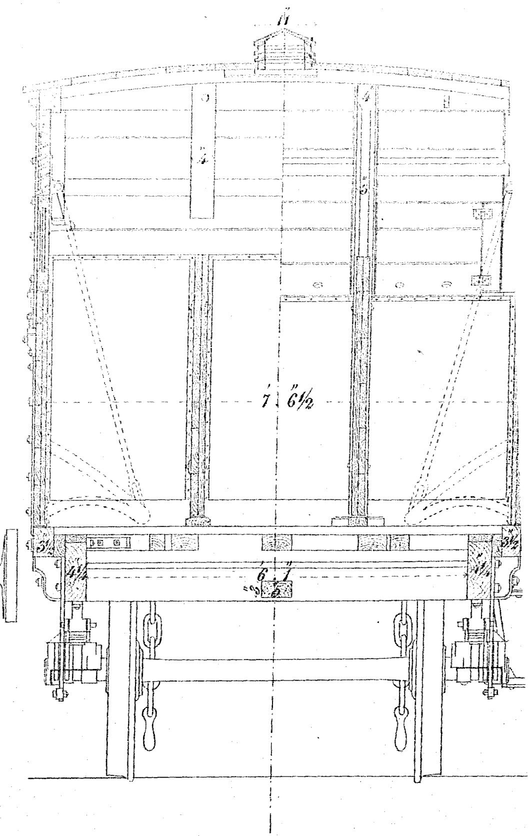
C.F. Cheffins lithog.

HORSE BOX.

ELEVATION.



TRANSVERSE SECTIONS THROUGH C. ON



WATERING APPARATUS.

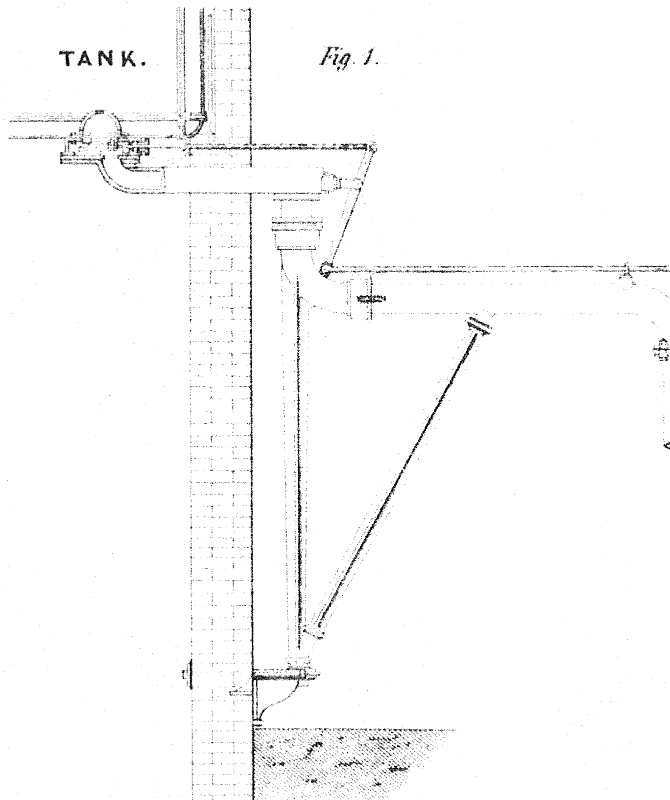


Fig. 1.

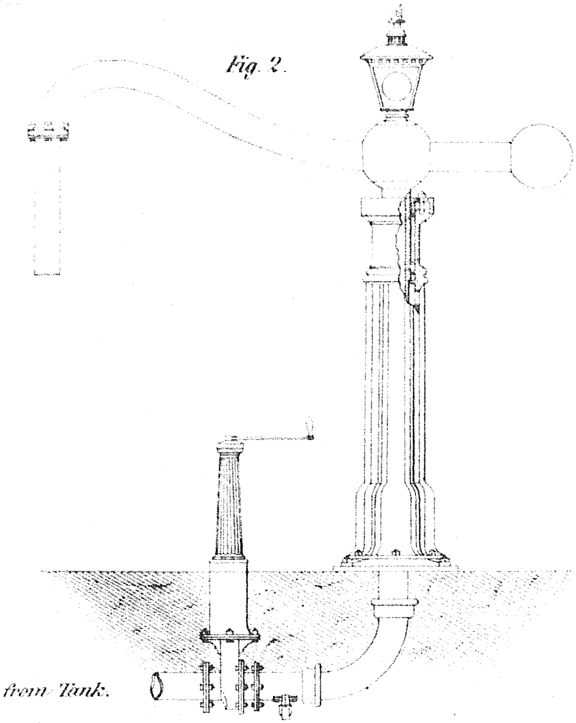


Fig. 2.

Scale.

Inches. 12 6 0 1 2 3 4 5 6 7 Feet.

John Weale, 59, High Holborn, 1850.

Fig. 1.

Plan of wrought Iron Turntable 13 feet diameter

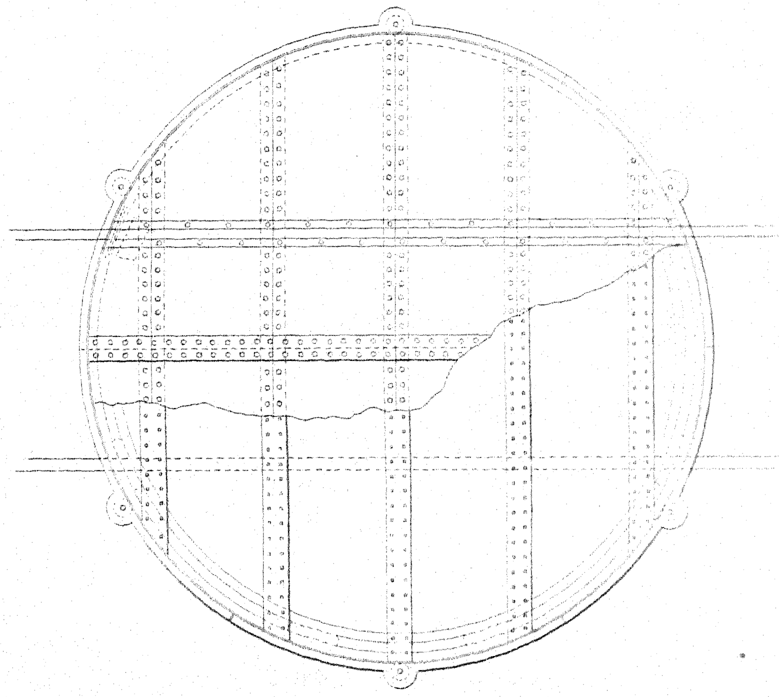
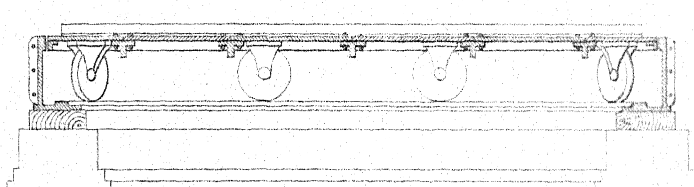


Fig. 2.

Crofs Section



J. W. Lowry fc.

Details of Rollers and Outside Rim

Fig. 3.

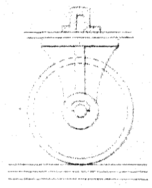


Fig. 4.

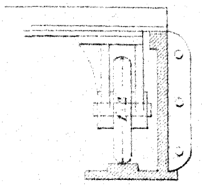


Fig. 5.

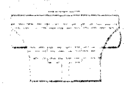


Fig. 7.

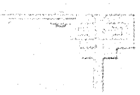


Fig. 8.

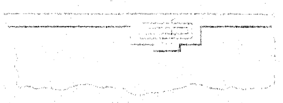
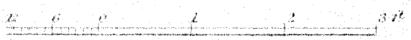
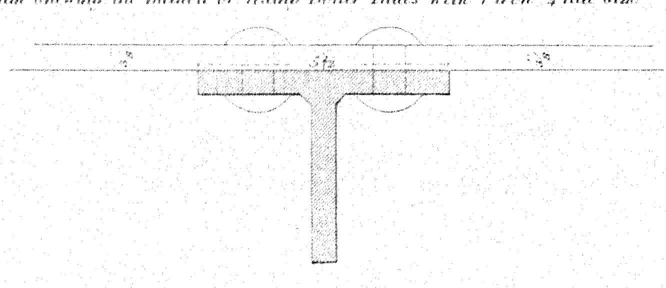


Fig. 9.

Details of Friction Rollers



Plan shewing the method of fixing Boiler Plates with T iron ¼ full size



EARTHWORKS.

Excavating.

FIG.1.

Longitudinal Section of Fig. 2.

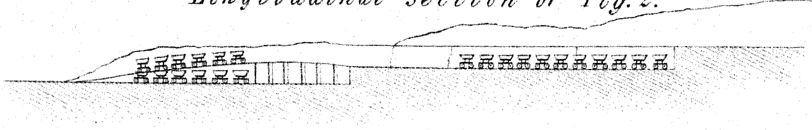


FIG. 2.

Plan of Fig. 1.

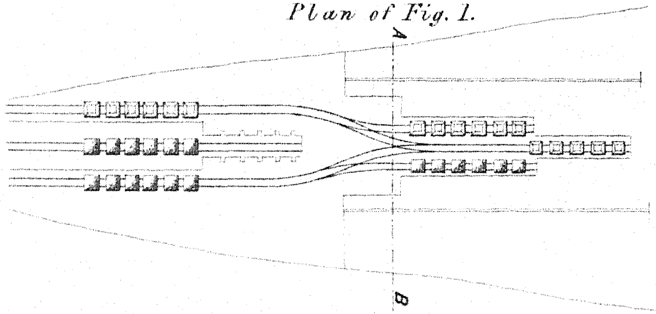
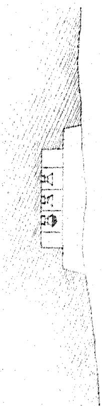


FIG.3.

Section on A.B. of Fig. 2.



EARTHWORKS.

Embanking.

FIG.1.

Section of Fig. 2.

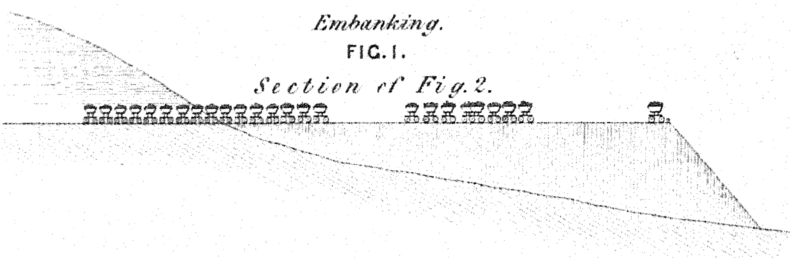
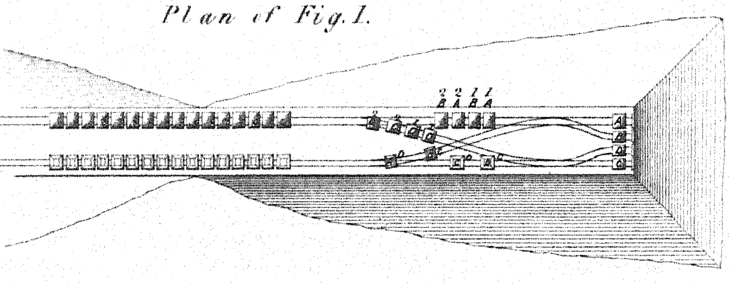


FIG. 2.

Plan of Fig. 1.



JOHN WEALE 59 HIGH HOLBORN.

tants as guides: the escort may, however, often be dispensed with, so as not to attract so much observation, and grey cloaks should be worn for the same reason; at the same time an uniform must be worn underneath, to prevent their being considered as *spies*, if taken. They should start for this purpose after dusk, so as to conceal, if possible, their intentions: to avoid being stopped by the enemy, they should not travel along the main roads, but must cross them as often as possible to examine their character: they should never halt long, except at single houses apart from the villages, and never sleep on two successive nights at the same place: they must avoid giving a clue to their intended route or object by their inquiries, or by letting their guides see them taking angles and drawing plans; and they must also be provided with two or three days' rations, to prevent the necessity for going into any houses whatever when there is danger of being taken.

A *map* of the country is usually required to be constructed, or at least, if there is not time or means for constructing one, as explained in the article 'Field Sketching,' a rough diagram must be made to shew the positions of the principal points, and of the rivers, mountains, forests, roads, &c.

A *memoir* or *report* is indispensable, to give an account of the features of the country and of the positions held by the enemy, and should be accompanied by an alphabetical list of the various places in a tabular form, so as to shew at a glance the resources and accommodation afforded at each.

The following Orders, given by Sir George Murray to the Officers of the Quarter-Master-General's Department during the Peninsular War, will serve as a guide in the compilation of reports, and the list of resources must shew in separate columns the number of men and horses for which there is permanent and temporary accommodation, the quantities of various kinds of cattle, carriages, food, fuel, and other resources to be procured, and the number of mechanics, mills, forges, &c.

Instructions to Officers of the Quarter-Master-General's Department.

"One of the first duties of the Officers of the Quarter-Master-General's Department is to acquire a knowledge of the country which is the theatre of the operations of the army: this supposes not only an acquaintance with the natural and political divisions of the country, and with its principal features, but also detailed local information on the following points:

"1st. The peculiar nature of each district of country and its productions; what parts of it are mountainous or hilly, and what are level; whether the hills are steep or broken by rocks, or if they rise by gradual and easy slopes, or if the ground is undulated only in gentle swells; whether the connection of the high grounds is obvious and continued, or if the heights appear detached from each other; in what direction the ridges run, and which is their steepest side; what is the nature and extent of the valleys, and, in like manner, what is the nature of the ravines,—where they originate, in what directions they run, and whether they are of difficult access or to be easily passed.

"Whether the country is barren or cultivated, and what is the kind of cultivation, —whether vines, olives, or corn (and, if the latter, what kind,) are grown, and in what parts it is most abundant; also what is the nature of the soil.

"If it is a country of pasturage, whether it is pastured by cattle, by sheep, or by horses, and in what numbers.

"What parts of the country are open and what are enclosed; also the description of the enclosures, whether small or extensive, formed of stone walls, ditches, hedges, or fences of any other kind.

"What parts of the country are wooded, and whether with full-grown timber or coppice-wood, also with what species of trees.

"What is the nature of the country with reference to the operations of troops; what parts are favourable to the action of Cavalry, and what for Infantry only.

"2nd. *The Rivers, lesser Streams, and Canals.*—The sources of rivers and the direction of their course,—whether they are rapid or otherwise; their breadth and depth, and what variations they are subject to at various seasons of the year; the nature of their channels and banks,—whether rocky, gravelly, sandy, or muddy, of easy or of difficult access: the bridges across them,—whether of stone or of wood; their breadth and length, and whether accessible to Artillery, and capable of bearing its weight.—The Fords, with similar remarks, and whether always passable, or at certain times and seasons only.*—Which rivers are navigable, from and to what points, and by what description of vessels or boats.—The Ferries, their breadth and the nature of the landing-place on each side; what description of boats is used upon them; how many men, horses, carriages, &c., each boat is capable of containing,—how much time the passage requires, and in what manner it is performed.—Canals, their course, breadth, and depth; the nature of the traffic carried on upon them; the number of boats usually to be found at different places, and their nature and dimensions; also, whether they are tracked by men or horses, or how otherwise navigated.—Lakes and inlets of the sea, their situation, extent, and boundaries; what description of vessels can navigate them, &c.; together with such of the above observations as are applicable to them.—Marshes, their situation and extent; whether passable for troops in any part, and whether they continue wet throughout the year, or exist only during the wet season.

"3rd. *Population, resources, accommodation for troops, &c.*—The size of towns and villages, and the number of their inhabitants; also whether they are well supplied with provisions or not; the number of houses, churches, convents, or other public buildings; whether the houses are large and commodious, or small and mean: what number of troops could be accommodated in private houses, and what in public buildings: what stabling or other cover there is for horses; whether the towns are walled or open, favourably situated for defence or otherwise, also if capable of being strengthened, and by what means. Similar observations in regard to detached convents, gentlemen's seats, farms or other separate buildings, are required; and plans or sketches of walled towns, defensible villages, or detached buildings, should always accompany the reports upon them.

"The number of carriages, horses, mules, or draught oxen, in possession of each town, village, or farm, should be stated, and what is the general means of conveyance made use of in the country; whether places are unhealthy or not; and if they are, whether there are any obvious local causes; also, whether they are generally unhealthy or only so at particular seasons.

"4th. *Roads.*—Particular information must be obtained respecting roads, in the description of which it is impossible to be too minute: the general nature of each road, and also all variations which occur in it from distance to distance, should be accurately described; whether the road has been regularly made, or appears to have been formed only by the use of the people of the country; whether it is fit for Artillery, or practicable for any description of wheel-carriages, for Cavalry or for Infantry only; over what descriptions of soil it passes, whether rocky or gravelly, sandy, clayey, or earthy, and to what injuries it is liable in bad weather; whether it is easily repairable or not; what materials are requisite for that purpose, and whether they

* See article 'Fords,' vol. i. p. 545.

are to be found in the neighbourhood; whether any bad parts of the road, or the narrow and embarrassed streets of any of the towns or villages, can be avoided by going out of the road for a short distance, as also whether any great improvement could be made in the general direction of any part of the road by adopting a new line altogether for a considerable distance; and what amount of work is necessary in either of these cases.

"Particular attention should be paid to the ascents and descents upon the road; whether they are gradual and easy, or abrupt, rugged or stony, having short turns or other difficulties; whether the road is wide enough in those parts which run along the sides of hills, and whether it is even or canted off the level, so as to be unfavourable for carriages.

"In those parts where the road passes between walls, or where it forms a hollow way between banks of earth, rocks, or other obstacles, its breadth ought to be measured; and it should be stated also whether it can be widened, or the obstacles which confine it removed.

"The ferries, bridges, fords, &c. met with on the road should be particularly attended to; the possibility of obstructing or breaking up the road, so as to prevent its being used by the enemy, or of destroying the bridges and fords upon it, should be stated: the means of effecting these objects should be pointed out, as also the labour and time requisite for such works.*

"The distances of the places along the road should be given, both in the measures of the country and in English miles, averaged as accurately as possible: the time required to travel the different distances at the ordinary walk of a man or of a horse should be also stated. The places to the right and left near the road should be mentioned, their distances from the road, and at what points the communications to them strike off from it.†

"Care must be taken that the names of towns, villages, rivers, &c. are spelt in the same manner as by the natives of the country; and when the spelling and pronunciation differ very much, the names should be written (in a parenthesis) as they are pronounced.

"5th. *Camps and Positions.*—All strong passes, posts, or more extensive positions which present themselves either upon the line of a road or in any other situation, as also all places favourable for encamping or bivouacking troops, either with a view to remaining there, or with reference merely to convenience on a march, should be particularly described; their situation, extent, facility of access, nature of soil, supply of water at all seasons, quantity and kind of wood, and whether in sufficient abundance for hutting the troops, or only for furnishing fuel.‡

"A sketch of the ground, upon a pretty large scale, should always accompany the Reports; those of positions should never be made upon a smaller scale than 4 inches to an English mile; general sketches may be made upon a scale of 2 inches to a mile, and tracings of roads upon a scale of 1 inch to a mile.

"The Officers of the Department ought to avail themselves of every opportunity that offers to verify and extend their information upon the points above mentioned; and the information obtained should be always put into such a shape that it may be transmitted to the head of the Department, or be applicable to the use of the General Officer under whom they are immediately employed.

"In all Reports they will be pleased to state distinctly what parts of the information which they contain rest upon their own personal examination of the objects in

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* *Vide* articles on 'Bridges' and 'Demolition.' † *Vide* annexed form.

‡ *Vide* article 'Castrametation.'

question, and what upon the authority of others; and in the latter case, they will mention the source of their information, in order that a judgment may be formed of the degree of credit to which they are entitled.

"They will consider it their duty to apprise the Quarter-Master-General of every reconnaissance report, sketch, &c., executed by them; whether done by order of the General Officer to whom they are attached, or upon any other occasion, as all their labours are understood to belong to the Department, and to be the property of the public.

(Signed) "GEO. MURRAY, Q. M. G.

"Cartaxo, Dec. 2nd, 1810."

In addition to the points mentioned in the above instructions, the Report should state to what extent the banks of the rivers are liable to be flooded by falls of rain, melting of snow, or breaking of embankments, and how long it usually takes for these inundations to subside; the alterations liable to be caused by floods in the direction or depths of the channels, and the periods during which the rivers are usually frozen over; what materials are available for making rafts, such as are afforded by timber-yards, the beams of houses, trees, &c.; what number of boats can be collected at given points within a certain time; the exact width of the bridges, the number and spans of the arches, the nature of their masonry or other materials, the facilities for fording the river near them, so as to prevent a column in passing over on the line of march being lengthened out by the narrowness of the roadway; the space available for deploying on each side, or for constructing works, as bridge-heads; the probabilities of certain parts of the roads being rendered impassable by the march of troops over them, and the means at hand for repairing them with fascines, rails of fences, &c.; also whether, in that case, carriages could be got through by merely sending Infantry to assist.*

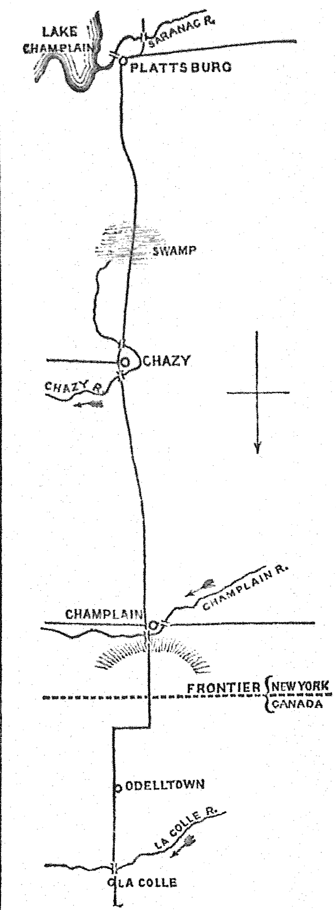
The Officers making a reconnaissance must take care to verify personally as much as possible of the information which they may obtain; but all persons who may be met with should be cautiously and separately interrogated, employing art rather than force,—inquiring about subjects of a different nature from that on which information is required, so as to lead to it *casually*, and writing down what is important without being observed, so as to prevent being suspected by the enemy, who, by sending out a few parties, would probably surprise them; to prevent which, the greatest precautions must be taken, particularly by keeping the horses ready-saddled at night. Prisoners or deserters should be interrogated as to the numbers, strength, and position of their regiments and divisions, the names of the Generals, the positions of detachments and of head-quarters, alterations of positions expected, latest orders given out, numbers of wounded or recruits, quantity and localities of provisions, artillery, siege, and bridge equipments; also whether the enemy are repairing any roads, bridges, &c., or constructing intrenchments; and inquiries must be made of the principal inhabitants as to the movements and positions of the enemy, as also the arrangement of their columns on the line of march.

Spies must be employed with great caution, making use of them so as to be checks upon each other, and giving them nothing in writing but what will serve to mislead the enemy; also paying them liberally, and, if possible, retaining their families as pledges for their fidelity.

The form given on the next page for Reports on particular roads has been found very useful, as it shews at a glance the information required, which must often,

* See 'Passage of Rivers.'

Distance. Total.	Distance. Inter.	Places on the Road, with Description.	Accommodation. No. of Houses.	Accommodation. Men, temporary.	Accommodation. Men, permanent.	Accommodation. Horses, permanent.	Distance to Places near the Road.	Sketch of the Road.	Distance to Places near the Road.	Difficulties on the Road, proportions of swamp and forest, description of houses, soil, fences, water, &c.	Positions to cover a retreat either way; bridges, ferries, fords, boats, &c.
miles.		Plattsburg—a shallow harbour at the mouth of the Saranac, protected by a wooden breakwater: on the south side are barracks of wood; a few houses of brick in the town; the rest are of wood, framed.	250	3000	1500	500			Malone, 50	Country level and well cleared, except at the swamp 9 miles from Plattsburg, — where there is a tangled cedar forest for half a mile.	
	12	Chazy—a large stone mill commanding the southern bridge; the rest of the houses wooden.	60	500	200	30	Chazy Landing, 3			Road good in dry weather, but clayey and tenacious after wet; the fences all wooden.	At Chazy is a good position facing either way, and another on the north side of Champlain, facing the south. The rivers are all fordable, and bridges all of wood.
22	10	Champlain lies in a hollow, quite commanded, and contains large stores and mills.	100	1000	400	50	Caribou, 2½		Perrysville, 7	Country undulating and cleared along the road; but there are broad belts of forest, in all directions, within half a mile of it.	
26	4	Odelltown — a scattered village.	30	200	100	10				The houses are all of wood, framed.	
29	3	La Colle, hamlet, with a good inn.	20	200	100	20				There is good water in wells and streams everywhere.	



however, be much more detailed than that here given: the approximate heights of the prominent points traversed by each should be marked upon the sketch; the difference of level required to obtain these may be estimated by noting the points where the horizon, if it were that of a plain or of the sea, would cut the sides of the hills, which may be considered to be on nearly the same level as the spot where the observer stands, from whence, by remarking the apparent heights of men, houses, or trees near them, the amount of the difference between them and other points may be judged of.

A reconnaissance by a body of troops, to discover an enemy's force and position, must be planned in accordance with the nature of the country, and its strength must depend very much upon the chances of being surprised: men should be detached to every commanding height near the road, to observe the movements of the enemy, and telegraph accordingly to the main column; also the Officer commanding must arrange his plans to secure a retreat, by remarking the points favourable for delaying an assailant, or likely to cover an ambuscade.

A sketch must be made shewing all the features of the country traversed, the positions of the enemy, the nature of the approaches leading to them, and of the obstacles protecting them, as well as the situation of field-works, artillery, and cavalry. Sometimes an attack made with much noise on one side of a position may draw off the enemy's attention from that where the reconnaissance is being made, and individuals may often creep close up to it under cover of hedges, &c., so as to insure a more satisfactory examination of the defences; but care must be taken not to compromise the retreat, and not to halt, except in open spots, the approaches to which can be seen for some distance; and it must be recollected that it is of great importance not to attract too much attention to the real object of the reconnaissance.

From the dust raised and the space occupied by the enemy's troops on the march, and from the number of their fires (calculating on about six men to each of the latter), their strength may be estimated; also it may be remarked, that if the glitter of their arms is brilliant, they are probably advancing, and if not, retreating.

The extent of cover from the enemy's fire afforded by hollow ground, &c. in front of his position must be carefully noted; likewise whatever can be discovered relative to the country beyond the enemy's position and on its flanks, as well as the movements taking place among the enemy's troops and carriages.

Reconnaissance of a Fortress preparatory to an Attack.—Having procured the best plan of it which can be obtained, and such information as the people living near it can furnish, an Officer must approach by daylight, with but few attendants, yet supported by small guards concealed in their rear, to verify and correct the plan and ascertain the best direction in which to advance for the purpose of examining the details more closely, which he will do afterwards at night with a strong guard; and by retiring gradually as day dawns, will be able to see most at that time without being discovered or interrupted.

The points most necessary to remark are the hollows and fences affording cover; the roads by which the guns and stores can be conveyed to the projected batteries without being exposed to the fire from the fortress; the material, height, and slope of the glacis, and the features of the country around; the depth of the ditches and of the water in them; the condition of the flanking defences; also the nature and position of the bâtardeaux, and state of the revetments, parapets, hedges, and other obstacles, &c., &c.

By the sound of tools, the appearance of scaffolding, &c., or by information received from the workmen, may be discovered at what parts repairs are going on or have been lately executed, as also what mine-galleries, retrenchments, &c. have been constructed; and the lightning-conductors will often point out the situation of the magazines.

Three ladders braced together, or a more permanent stage, may be employed sometimes advantageously for watching the operations of the besieged.

After it is decided on which side to attack, further details of the plan of the works may be obtained by taking the prolongations of the parapets when the shadows mark them most distinctly, and thus a more accurate plan for the Attack may be constructed, on which the projected approaches can be laid down.

REPORTS, MILITARY.—The Editors have been requested to insert an article on the subject of framing Military Reports, to assist the memory of an Officer upon any emergency in the field; and in accordance with this wish the following suggestions are offered:

1. It has been found convenient, and it is directed by an order of the Master-General and Board of Ordnance, that all Reports should be written half-margin on foolscap paper, and each paragraph numbered: this arrangement enables the superior Officer to whom the Report is addressed to make marginal notes, and the numbering of the paragraphs affords an easy reference to the several parts of the subject.

2. All Reports should be accompanied by drawings, either as sketches of the ground, or views of the principal features; and the more they are illustrated by vignettes and diagrams, which may be given on the margin or in the paragraphs of the Reports, the more interest will be given to them, as facilitating a quick comprehension of the subject.

3. Many parts of a Report may be given in a tabular form, which should be done when possible.

4. An early attention to the object of the Report, and the instructions or orders received for making it, will save much trouble: it is also necessary to arrange the subjects in the order of their relative importance, so time may not be lost in seeking for information of little value.

5. An important consideration is the condensation of facts in the smallest possible space, in logical order, so as to keep up the interest of the subject,—and by inserting unimportant details only in notes or in an Appendix to the Report. Care should be taken that little extraneous matter is given; and if any thing foreign to the purpose of the Report should be considered useful, it may be placed also in the Appendix, with an allusion to it in the body of the Report.

6. The purport or substance of each paragraph of the Report should be briefly inserted in the blank half-margin side of the paper; this enables the reader to recur to any part without trouble.

7. Military Reporters should be careful in recording hearsay statements, and offering opinions on surmise; and if vague, the authorities should be quoted, and the value of the evidence stated: facts are what is required, based upon ocular demonstration.

8. In framing a Report, much valuable information will be found in this work, under the heads of 'Field Sketching,' 'Geology,' and 'Reconnoitring.' In this last the several subjects necessary to notice are given, and the most important points of each are inserted in detail. The articles on the 'Passage of Rivers,' the 'Construction of Roads,' and 'River Navigation,' also 'Statistics,' will afford valuable information to the Reporter, according to the tenor of his instructions.

9. The application of ground to military operations, whether offensive or defensive, for strategetical or tactical purposes, may be considered the most difficult of tasks to a Military Reporter, and few opinions should be given, except those formed from incontrovertible facts; and assertions that a river is impassable, a country inaccessible,

a place impregnable, and roads impassable, should only be offered on most accurate information; and if not from personal inspection, the authority must be given. To suggest that particular sites afford good positions for offensive or defensive tactical operations, or that they are well suited for intrenched camps, posts, or positions for strategetical operations, should be given hypothetically, if not based upon a thorough acquaintance with the country, and some knowledge of the Art of War.

10. Finally, in arranging the Report, the classification of matter under different heads should be attended to, and subjects separated, keeping the descriptive, statistic, political, and military parts distinct, as well as other points unconnected with each other.—G. G. L.

RIVER AND INLAND NAVIGATION.*

SECTION I.—RIVERS.

General Remarks.

1. Rivers, as far as they are applicable to the purposes of internal navigation, may be regarded as natural canals whose section, inclination, and speed, or rate of flow, vary within limits of considerable range; and the volume of water they carry, and the nature of its movement, are proportionately affected by such variations. Running waters are also utilized as motive powers, not only for the mills placed immediately upon them, but also for the descending navigation.

2. Those who may desire to study in detail the laws which connect the general phenomena of the elevations of the mountain ridges, and the direction of rivers, are referred to the works of Messrs. Lamblardie, Brisson, De Torcy, and Denaix. Sir C. Lyell's incomparable work, the 'Principles of Geology,' and the more modern treatises upon Physical Geography, contain much interesting information bearing upon this branch of practical science.

3. For present purposes it will be sufficient to consider rivers as presenting, from their source to the places where they fall into other rivers or the sea, the following characters: In plan, they present a water section, or line, which widens with more or less regularity. In longitudinal section, they present concave curves both at the bed-line and at the surface (with occasional exceptions): these curves are not always either concentric or parallel one with the other. The total length measured upon the longitudinal profile in all cases exceeds that measured in a straight line between the two extremities.

4. When rivers fall into a sea subject to tidal influences, or into another river whose level is variable, their plans and profiles vary unceasingly. When tides act upon them, their variations are periodical, and follow the laws which regulate the tides; that is to say, the spring and neap tides, the ordinary, or the equinoctial ones, affect the river-waters in the same manner that they do those of the sea.

5. The speed of a river, or its rate of flow, would continually accelerate, independently of the variation in the volume, if the muddiness of the waters, and their friction upon the bottom and sides of their bed, did not exercise a retarding influence. These resistances augment in proportions even more considerable than the rapidity of the current, and thus counterbalance the influence of the fall, and establish something like an uniformity of flow. It is also to be observed, with regard to the course of all rivers carrying them through plains, that in the latter portion of their passage to the sea the velocity becomes to a great extent equalized by the diminution of the rate of fall.

* By George R. Burnell, C. E.

6. Moreover, the flow is not the same in the whole of the transverse section of a river. In the cases where tides do not act, it is the greatest in the portion called by continental Engineers the *thalweg*, which, in fact, is defined by this identical phenomenon. Beyond the thalweg there are zones in which the water is either stagnant, or even at times where it has a movement in an opposite direction to the usual current, especially in the cases where the section of the river widens out unexpectedly. These currents are sometimes called 'backwater,' or counter-currents. A very plausible explanation of them has been given by Venturi, in a very remarkable treatise upon 'the lateral Communication of Movement to Water.'

Mean Velocity.

7. In the thalweg itself, also, the flow is not the same at the bottom as at the surface of the water. In rather shallow rivers, the maximum of speed appears to be at the surface. It is usually considered that the average speed of water flowing uniformly in the same direction is $\frac{4}{5}$ths of that of their surface. This proportion was ascertained by the researches of Dubuat and De Prony. Navier, moreover, observed that when water moved in straight lines parallel to the axis of the bed, (supposed in this case also to be straight,) the mean speed and the maximum speed of the surface of the thalweg approached each other in proportion as the bed became less, and without any reference to the transverse section. If the vertical depth of the water were very small, and the width very great, he found that the mean speed was 0·64 of the maximum. If both were very great, it assumed the proportion of 0·41.

Velocity of Stream.

8. It rarely happens that we meet with rivers whose beds fulfil the requisite conditions of being thus in a perfectly straight line. For all practical purposes, then, we may adopt, for all speeds of water between 8 feet to 5 feet 8 inches, measured upon the surface, the following formula as representing the average speed: $v = \frac{4}{5} V = 0{\cdot}8\ V$; in which v = the mean or average speed, V = the speed upon the surface. The above formula gives results which are superior to those we meet with in reality, when our examinations are made upon large streams; for the Seine has an average speed in which $v = 0{\cdot}62\ V$; the Neva, $v = 0{\cdot}75\ V$.

Velocity at Bottom.

9. Dubuat's experiments shewed that the speed of the water at the bottom, or immediately upon the bed, may be expressed thus, making U = the speed sought,

$$U = 2v - V;$$

or, supposing $V = 1{\cdot}25\,v$, $U = 0{\cdot}75\,v$, or $v = 1{\cdot}33\,U$.

The consideration of these questions is of the utmost importance to the Engineer about to carry into effect any works either for the improvement of the navigation, the defence of the banks, or the construction of bridges. In order to guard against the corroding effects of the current, it is necessary to construct the foundations of the works in such a manner, and of such materials, as are not likely to be removed by it. It becomes, in fact, necessary that the bottom of the waterway be of a nature to resist the power of the stream to carry off the materials of which it is composed.

10. Experiments have shewn that the different substances named below are carried off by waters flowing at the respective speeds mentioned in connection with them:

Soils moved.

	Speed per second. ft.	in.
River mud, liquid earth, &c.	0	3
Brown pottery clay	0	$3\frac{1}{4}$
Common clay	0	6
Yellow sand, loamy	0	$8\frac{1}{2}$
Common river sand	1	0
Gravel, size of small seeds	0	$4\frac{1}{4}$
,, of peas	0	$7\frac{1}{8}$
,, of beans	1	$0\frac{1}{2}$

	Speed per second. ft.	in.
Coarse ballast	2	0
Sea shingle, about 1 inch diameter	2	2
Large shingle	3	0
Angular flints, size of a hen's egg	3	3
Broken stones	4	0
„ agglomerated, or soft schistose rocks	4	4
Rocks with distinct layers, 'flakey' rocks	6	0
Hard rocks	10	0

It may be observed that very moderate speed enables the water to carry off the lighter soils, such as are usually found in the beds of rivers. Hence, to a great extent, the frequent changes they are subject to. The destructive action of the current is augmented by the beating of the waves, the abrasion by floating ice, the alternatives of wetness and dryness, and especially by frosts. Aquatic plants protect the beds in a very sensible manner, however, when the depth of water does not exceed much more than 6 feet.

Obstacles to Flow.

11. Any unusual obstacle opposed to a current, whether naturally or artificially, acts by heaping up the waters on the up-stream side, and by accelerating their speed on the down-stream side. If the bottom be of a nature to yield to this increased speed, an excavation is necessarily formed. When one of the banks of a river yields to the action of the current, the elbow thus formed has a tendency to increase rapidly. The depth of the water augments, and the currents deposit the matters they hold in suspension upon the opposite side, which becomes gradually convex whilst thus silting up. The curves or bends thus formed advance gradually from the up-stream direction to the down-stream.

M. Defontaine observed that upon the Rhine, a river with a bottom of sand and gravel, exposed to sudden floods of remarkable violence, the natural bed of the river was not affected by the formation of new elbows, when the radius of its curvature was above 8300 feet, at least to any serious extent. His experience led him to adopt one-half of that radius for the works in masonry he constructed to defend any advanced parts of the banks, in order to protect them against the corroding action of the current at their feet.

Action of Irregularities in the Bed.

12. Any sudden depression, any abrupt projection, either upon the banks or even in the bottom, produces a species of whirlpool and backwater, attributed by Venturi to the lateral movement of the waters. If the bottom is susceptible of being carried away, there are excavations formed in some places, the materials of which are deposited at distances, which of course vary according to circumstances. We find also that the meeting of two rivers, of the same volume and speed, at an angle nearly of 90°, not only produces an oblique final movement compared with the direction of the primitive current, but also a series of these whirlpools.

Action of Spurs.

A spur projecting into the river also determines a backwater both upon the up-stream and the down-stream side. If the bottom be soft, the point is liable to be undermined and carried away; a silting up takes place in the down-stream angle of the spur, which also sometimes takes place on the up-stream side. This, however, more properly belongs to that portion of the subject which treats of the defence of the banks of rivers.

Action of Floods.

13. Another very important cause of perturbations in the ordinary course or flow of rivers is found in floods, which, from their velocity and the immense volume of water they bring down, often affect the bed and the sides of rivers in a dangerous manner. Sir C. Lyell mentions one flood in which the waters attained a velocity of

no less than 36 feet per second. Such catastrophes are rare, it is true; nor can all the science of the Engineer guard against their effects. But such rivers as the Rhine are known to have risen 66 feet in a single day, and Engineers may often be called upon to resist the action of such floods. These are generally charged with the maximum of foreign matters they are able to hold in suspension. When their intensity diminishes, or the speed of the current is slackened by any accidental circumstance, the waters deposit gradually, and in the order of their specific gravities, the substances they contain. A different relation is thus established between the section of the river, the volume of the water, the speed, the fall, and the form of the outline of the bed. Towards the down-stream portions of the river, the section will be found to have become less able to carry off another flood; and if the sides resist less than the bottom, the river will spread out, often into several branches, which, in the dry seasons, will not present a sufficient depth of water.

Banks at Mouths of Rivers.

14. In the lower portions of a river, where it falls into the sea, there are other causes for the silting up of the channel in addition to those already mentioned. Thus the sea-waters carry up with the tides shingle, sand, or mud, according to the prevailing winds, or the agitation of the sea acting upon the rocks forming the coast. These matters, as well as the alluvium of the fresh water of the upper countries, are deposited when the speed of the currents is arrested by slack tides; and it is thus that in such rivers as the Thames, the Seine, the Loire, the Rhône, the Rhine, or the Po, the channel of the embouchure continually shifts about amongst the numerous banks.

Raising of Bed.

15. The natural tendency of rivers to raise their beds by the gradual deposition of the matters they contain in suspension also of necessity raises the mean level of their usual flow, and requires that embankments should also be raised in the same proportion. The banks of the Po in this manner have been gradually raised until they are from 40 to 45 feet above the surrounding country. Notwithstanding all the precautions taken to preserve them, they must inevitably yield, sooner or later, to the action of the stream; which will create for itself a new course to the Mediterranean, to be in its turn silted up and abandoned, like its predecessors. Such deviations in the bed of the Po are far from rare, even in historical periods; and similar causes appear to produce analogous results at the embouchures of such rivers as the Ganges or the Mississippi.

Natural Barrages or Dams.

16. In addition to the multitude of these causes which tend to modify the beds of water-courses, we may observe that, especially in rivers which flow over gravel or sand, instead of following an uniform law in the diminution of the fall and the speed from their source to the sea, there are alternately zones of still water, in which the speed is hardly perceptible, and in which there is a great comparative depth of water; or 2ndly, there are rapids, or shallows, generally placed near the bends of the rivers, where the inclination of the bed, and the speed of the current, are considerable, and where there is but a small quantity of water. These shallows form, in fact, natural barrages, which raise the plane of the waters in the direction of the up-stream. In some cases they are occasioned by projecting portions of rock, which have given rise to the formation of banks in the channel.

Gauging a River.

17. M. de Prony's formula for ascertaining the volume of water in a river, $v = \sqrt{0{\cdot}005163 + 3233{\cdot}428\ \mathrm{R\,I}} - 0{\cdot}07185$, or more simply $v = 56{\cdot}86\ \sqrt{\mathrm{R\,I}} - 0{\cdot}072$, may serve in gauging any stream, provided we can find a portion of its length, at least 400 yards in extent, in which the section is constant and the inclination uniform. A transverse profile gives the section of the water, and the outline of the water edge of the bottom and sides, the 'perimètre.' From these elements we can easily ascertain the mean radius of the perimètre R. The fall upon the line of the axis is

expressed by I. Substituting the values of R, I, and v, obtained from actual observation, we arrive at the volume discharged. In all these formulæ, unless especially mentioned to the contrary, v represents the mean velocity of the current.

Another method of gauging a river is to determine simply the maximum speed at the surface. This is ascertained by a series of observations to be frequently repeated upon floats thrown into the stream, and allowed to travel as far as possible in the part of the river where the current is most regular. The mean speed of the surface thus obtained multiplied by 0·8 gives the average speed of the whole volume. The average section is then taken from as many profiles as possible, and the mean speed of the whole volume multiplied by the surface thus found gives the average discharge. This means of ascertaining the discharge is only approximative; it is therefore advisable to establish the results upon as great a number of carefully-noted observations as possible.

Classification of Rivers.

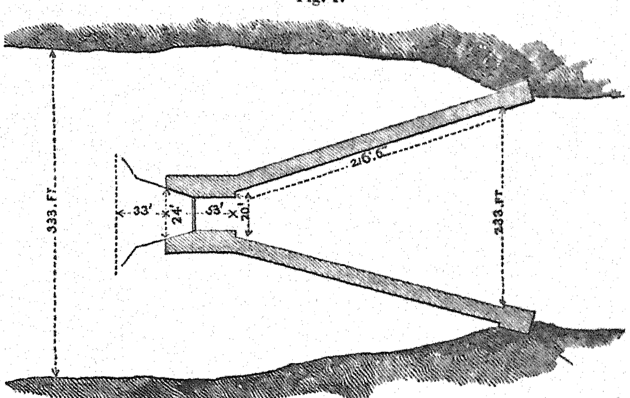
18. Rivers may be divided into two classes, viz. navigable, or floatable, according to their adaptation to the wants of commerce.

A river is said to be 'floatable' when rafts of fire-wood or of lumber can habitually meet with a sufficient depth of water, and a sufficient width of section, to descend either by the natural course of the river, or by retaining the waters in artificial basins, from which they are allowed to escape at regular intervals. In England we rarely have occasion to use rivers in this manner; our timber-forests are so few, and so peculiarly situated, as not to require the imperfect navigation in question; but in our Colonies it would doubtlessly be often advisable to direct attention to rendering the mountain streams useful by regulating their flow. An excellent example of the manner in which a shallow irregular river has been made to render service to the kind of navigation under consideration, is to be found in the Yonne, above Auxerre.

Dams and Sluices in floatable Rivers.

19. A series of dams is thrown across the river, which keep up the waters in a manner forming a set of locks of still water, in which the trains of wood are formed, and floated to the sluices placed in the dams. The sluices are opened in proportion to the supply of water.

Fig. 1.

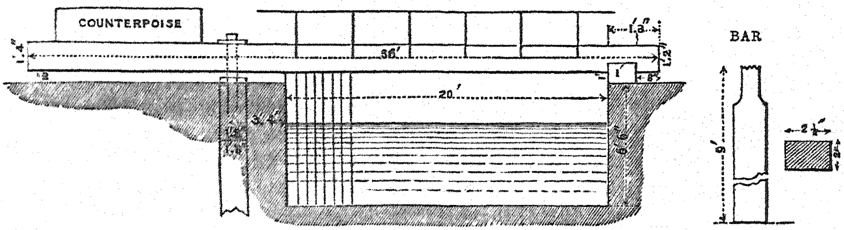


Plan of Dam at Régilbert, on the Yonne.

The sluices are mostly formed of small blades of wood, about 9 feet long by 2 inches wide and 2½ inches deep. They fit against a groove in the bottom sill of the water-way, and against a locking bar which turns on a pivot. When it is desired to use them, the lock-men draw the bars one after another, and turn the locking bar aside,

which operation is effected in less than eight minutes, provided the opening does not exceed 26 or 27 feet. The width of these sluices is made from 1 foot 4 ins. to 2 feet more than that of the trains or barges to be passed; and the walls should splay out immediately above and below the passage, with an estacade to defend the entry. These sluices have falls varying from 2 to 4 feet, but the latter is dangerous; their floors in the passages should be from 28 to 34 feet long. It is essential to observe that both the floor, and the walls in prolongation, require to be defended by piles and sheeting piles; for the opening of the sluice invariably causes a cataract.

Fig. 2.



20. The best position for the sluice is in the centre of the dam, as far as the preservation of the works is concerned; but for the purposes of navigation it is desirable to bring it as close as possible to the towing-path. The waterway should be contracted also for a distance of from 350 to 500 feet beyond the end of the floor. If it be necessary to combine a lock with the sluice, a circumstance very likely to arise when the river, after receiving several affluents, begins to acquire a considerable volume, the lock must be placed in still water on the opposite bank to the sluice. This last must be at the head of the chamber upon the upside of the lock, which it is desirable to place at a distance of about 80 feet from the end of the dam. Care must be taken to protect the side and tail walls of the lock from the cataract produced by the sluice.*

It is to be observed that dams across a river affect its level to distances considerably beyond the point where the line of their crown meets the line of the natural flow of the water. They appear, by retarding the velocity of the current, to heap up the waters anormally in a proportion which augments with the rapidity of the flow.

Navigable Rivers. 21. A river is said to be navigable either by means of sails, by the use of oars, or by towing. Navigation may take place either upwards or downwards; but in either case the river should offer sufficient width and depth of water for the movement of boats. There is, however, a limit of velocity in the current beyond which there is danger for the descending navigation, and excessive expenditure of water for the ascending.

Navigation by sails can rarely be practised in rivers, owing to their want of width and depth, their windings, and to the fact of their being usually enclosed in deep valleys. Towards the mouths of the rivers these unfavourable conditions disappear, and we find that in such as the Thames below the bridges,—the Seine between Rouen and Havre,—the Loire between Nantes and the sea,—the Garonne between Bordeaux and the sea,—navigation by means of sails takes place under tolerably favourable conditions.

The force of the wind, even when favourable, is rarely employed in ascending

* The minimum width of a floatable river is 13 feet; its minimum depth at the moment of flashing should be 1 foot 8 inches.

rivers, unless the speed be below that produced by a fall of at most 3 in 10,000, with a feeble width and a comparatively great depth of water.

22. The utmost limit of the fall of the bed of a river at which it was formerly considered safe to descend, or economically possible to ascend, was when it attained from 5 to 6 in 10,000. The progress of mechanical invention has modified the practice of commerce in these matters; and at the present day the Rhône, which has a fall of from 7 to 8 in 10,000, is navigated with great advantage. The River Lys in Belgium, upon a certain portion of its length, has a fall of about 5 in 10,000, in the district where the navigation is very active. It is supposed that in this case the aquatic plants, which it is forbidden to cut, act so as to retard the force of the current.

The boats used in commerce for River Navigation are of variable widths; from 6 feet 6 inches wide to 23 feet upon large rivers, with a draught of water varying from 2 feet to 6 feet 6 inches when loaded. Their length is of course regulated by the sinuosities of the channels and the width of the waterways, and it is often carried as far as twelve times the breadth. On some of the continental rivers it is very common to see barges 233 feet long by 23 feet wide, drawing 6 feet 6 inches of water, and able to carry 500 tons. Such enormous vessels are not in use in our own country, for the flow of the tides upon our coast usually runs so far inland as to obviate the necessity of the transhipment immediately upon the sea-board, for which positions the large barges in question are the most economical. It were desirable, however, that the barges to be employed on our East Indian rivers were constructed somewhat upon the models of those used upon the Lower Seine or the Loire.

Position of Towing-path.

23. We see thus that a river may be navigable by different means, according to the way in which we consider it; that is to say, whether in the ascending or descending direction, the draught or the tonnage of the boats employed, or the total length of time in the year during which it is navigable. In the latter case, it often becomes necessary to make a deduction for the low or for the flood waters. The first do not leave a sufficient depth of water for the boats to be able to travel; the latter often give rise to such velocities of the currents as to render it dangerous to navigate the rivers.

24. The movement of boats upon rivers is effected in the direction of the ascent, either by the oar, by towing, by animal force or by steam power applied in various ways.

Effort of Traction.

A horse is supposed to be able to exert upon a good Macadamized road a force of traction equal to twenty times the muscular effort employed. This is assumed to be equal to one hundred weight, so that his load on a road of this kind, while moving at the rate of about a yard per second, is one ton.

On a paved road the load becomes one ton and a quarter.
On a railway it is about ten tons.
Whilst in still water it is sixty tons.

On the Meuse, the power of a horse drawing against the stream, flowing at the rate of about 3 feet per second, with a depth of water of 3 feet 4 inches, and a discharge of 1225 feet cube per second, was found to be equal to 25 tons when moving at the rate of two miles an hour.

Experiments made on the canals of the North of France, in still water, shew that the resistance is about 0·0006 of the load, when the rate of movement is 3 feet 4 inches per second. On the canal of Givors, where men haul at the rate of one foot per second, the resistance is only 0·00014 of the load.*

* The effort necessary to draw a boat for an indefinite length through still water is represented by the formula

$$F = K \frac{A V^2}{2 g}; \text{ in which}$$

25. Formerly it was considered that the resistance increased in the ratio of the square of the velocity; but Mr. Scott Russell's experiments upon the Caledonian Canal appear to shew that this law does not hold good when the velocities exceed from 10 to 13 feet per second. The explanation of this apparent anomaly is usually found in the facts,—that in great speeds the surface exposed to the resistance of the water was diminished,—that a void was formed at the after-part of the moving body, and that the velocity of the water rushing back to fill this void was less than the speed attained by the hauling. Mr. Russell also noticed that the water was heaped up in the form of waves in front of the boat, and that these waves carried it, in fact, over passes where there would not have been, otherwise, a sufficient depth of water.

The laws thus discovered, without, however, our having obtained any satisfactory explanation of them, were endeavoured to be applied both in England and France. The success of their commercial application has been hitherto very equivocal, for the backwater and the beating of the waves upon the banks necessitated the paving of the latter in dry pitching, at least wherever the level of the waters was displaced by the movement of the boats. It also became necessary to Macadamize the towing-path, to allow the horses to travel at the requisite speeds. This question will, however, be treated more in detail under the head of Canal Navigation.

26. In River Navigation, the towing-path should be placed on the side where the water is the deepest, and immediately upon the banks of the river; in order that, firstly, there may be as few impediments to the passage of the cords as possible; and secondly, that the direction of the haulage be not too oblique.

It is also desirable to place the towing-path under the prevailing wind, in order to diminish as much as possible any action it might have in retarding the progress of the boat. The best width for a towing-path appears to be about 13 feet.

Independently of the towing-path, it is necessary to have mooring-posts on the opposite side of the river; and occasionally it is necessary to haul on both sides of the river, to maintain a boat in the navigable channel. It becomes then indispensable to have a kind of secondary towing-path on the opposite side, which, however, need only be 6 feet 6 inches wide on the crown. Both these paths must be maintained at sufficient heights to keep them above the water so long as the navigation can be carried on with safety. When that would be accompanied with danger, it is rather desirable that the paths be overflowed, so as to force the boatmen (always reckless) to suspend their operations.

27. In the construction of Bridges, it is desirable that the towing-path should pass under the land arches in such a way as not to render it necessary to detach the tow-rope. But in order to effect this, it is indispensable that the navigable channel should be near to the towing-path. Should this not be the case, it becomes necessary to let in rings, or to drive in mooring-posts, or to place buoys at the opening of the arches, to fasten the boats to whilst the tow-rope is being passed through the bridge.

F is the force of traction represented in tons.
A is the greatest width of the sunk surface.
V is the speed of the boat per second.
K is a coefficient, varying with the form of the boat.
g is the accelerating force of gravity.

The coefficient K may range from 1·10 to 0·12, according to the sharpness of the bows of the boat, or the presence or absence of a poop. In a canal, inasmuch as the section of the boat is greater in proportion to that of the water surface, the relative velocity of the current on each side of the boat is increased, and consequently the motive power requires to be augmented in the same proportion.

Any secondary streams intercepting the line of the towing-path must be bridged over in such a way as to offer no obstacle to the tow-line.

Works for the Preservation of the Banks and of the Bed of Rivers.

28. These are of two descriptions; sometimes they are intended to preserve the neighbouring lands from the corrosions of the stream; sometimes for the purpose of maintaining the latter in its proper direction, and at a regular distance from the towing-paths. The dredging works for the purpose of clearing the alluvial deposits may be included in this category.

In rivers which run with great velocity, such as the Rhine, the Rhône, and the Dordogne, these works are of the very highest national importance. In some cases the rivers run between the territories of nations at war with each other, as in the case of the Rhine; at others they traverse consecutively several states, as the Danube or the Po. The lower Rhine, whose floods formerly spread themselves over nearly the whole width of the valley in which it flows, has been gradually confined within its present bed by a series of embankments about 10 feet wide on the crown, which are disposed occasionally in several nearly parallel lines; so that if one embankment gave way, its ruin would only affect the portion of land it immediately protected. The banks of the Loire, between Orleans and Angers, answer the same purpose; although, from the fact of their being only single, some serious devastations have resulted from their rupture.

The overflowing of the freshets of such rivers as the Rhine, the Rhône, and the Loire in France, and of the Arno and Po in Italy, have produced the following result; viz. that the zones in the immediate proximity to the river are generally more elevated than those which are farther removed and upon the extreme edge of the valley. This is to be accounted for by the fact that the great floods deposit near to their banks the heaviest and most voluminous matters they hold in suspension, and that they are far less loaded when they spread out over the plain. From this cause marshes are eventually formed; because the rain and spring water, being unable to flow into the river channels, remain upon the surface of the land.

29. One of the cheapest, and at the same time it is one of the most effectual, methods of protecting the bed of a river, is by means of planting aquatic trees, such as the willow, &c., on both its banks. The roots of these trees spread very rapidly, and in themselves form the first defence of the bed of the river, as also of the banks. At the same time, inasmuch as they retain the mud which may be in suspension, they serve also gradually to raise those parts where they are planted. It is, however, necessary to execute such plantations on both sides at once; otherwise the defence of one side will but serve to increase the force with which the waters attack the other.

Rectification of the Midouze.

A very remarkable work of this description, which, it may be added, has been attended with signal success, was that executed for the purpose of rectifying and regulating the bed of the Midouze, between the Port de Marsan and its embouchure in the Adour, for a distance between 25 and 26 miles. The width of the pass created varied between 71 feet and 91 feet; the variations in the width being equally, or nearly equally, divided into four parts; and the limits of the new bed of the river were comprised between two concentric curves.

The original bed of the river was very wide and irregular, being formed in the midst of moveable sand-banks, through which the waters found a channel shifting almost at the caprice of every wind. The waters of the Midouze, even in their normal state, carried down great quantities of mud and sand. The system adopted

was, to form spurs in a kind of wattling, which were connected at one end with the bank, and at the other projected into the stream as far as the line of the intended new channel. These spurs were inclined at an angle of $\frac{1}{10}$ of that formed by the line of the current with the axis of the new bed.

The spurs were placed at distances of 133 feet apart, and exactly opposite to each other when they were to be fixed to the banks on both sides. They terminated towards the stream by returns in the shape of the letter T, each of whose branches was about 17 feet long.

The spurs were formed of pickets, placed 1 foot 8 inches from centre to centre. These pickets were of willow, of from $3\frac{1}{4}$ inches to 5 inches diameter; they were driven at least 4 feet 6 inches into the ground, leaving 1 foot clear above the level of the ordinary low water. Between these pickets, a wattling of 3 feet 4 inches mean height was executed with branches of willow between 7 feet and 10 feet in length, and about 1 inch in diameter. They were kept in their places in the upper part, so as to prevent their rising during floods, by means of oak plugs driven through the heads of the pickets. Long poles, about 10 feet in height, were placed on the opposite side to the towing-path, to indicate the waterway.

Independently of these main spurs attached to the banks, two minor spurs, about 44 feet 4 inches from centre to centre, with returns measuring 33 feet over both branches, were inserted between the main spurs. The object of their insertion was to facilitate the deposition of the mud and sand, and thus prevent the backwater from overthrowing the main spurs.

The minor spurs were composed of young trees of from 4 to 6 inches diameter; the length of the trees and their branches was not less than 10 feet; the diameter of the branches 5 feet. They were sunk in such a manner as to present their trunks constantly towards the pass, so as to direct the currents towards the new channel. Their direction was the same as that of the main spurs, that is to say, at an angle of $\frac{1}{10}$ of the one formed by the axis of the river, or new bed, with the current. The trees were fixed at distances of 10 feet apart. Strong pickets were driven in through the branches, so as to form an additional tie, to which the trunk of the next tree was attached. Of course the pickets followed the inclination of the first range of trees, and strong oak pegs were applied to prevent the branches from rising too far on the occasion of floods.

30. A pass, or waterway, was opened between the main spurs above described, to a depth of at least 1 foot below the lowest summer waters, and all the sand or mud thus extracted was thrown between the different spurs in such a manner as to add to their stability.

As soon as an artificial bank was thus formed by means of the excavations of the pass, and the gradual deposition of the matters in suspension in the waters of the river, means were adopted to defend it by plantations consisting of slips of willow, osier, poplar, or other aquatic trees, placed at distances of 6 feet 6 inches apart, and inclined so as to break any current which might be formed beyond the regular pass. Heath and grasses were planted between these in such quantities that 1 lb. of seed was used per acre. The slips of all the trees, except the osiers, stood about 6 feet from the ground; these last only stood up about 8 inches.

This method of forming the bed of the Midouze succeeded remarkably well, and was carried into effect at comparatively trifling expense. In many of our Colonies a similar system might probably be advantageously adopted. A detailed account of this work will be found in the 'Annales des Ponts et Chaussées' for the year 1831.

31. The effects of the action of running water upon different beds are, however, so

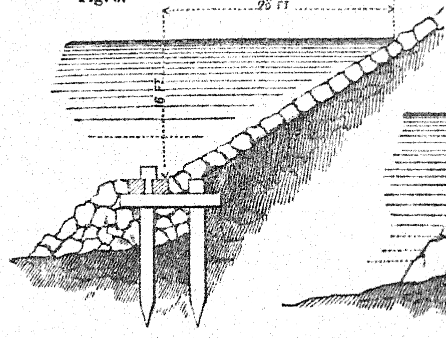
various, that what is highly successful in one case becomes utterly ineffectual in another. For instance, in the Loire, transverse spurs, even when executed in solid masonry, fixed to one bank and advancing far into the stream, produce very uncertain effects upon the width of the waterway. The excavations they form on one side are, in fact, very often accompanied by silting up on the other, or at points a little lower down the stream on the side attacked, so that the bed they create is very irregular and unequal. Indeed, as a general rule, it may be said that the only certain mode of deepening the bed of a river is by the establishment of longitudinal embankments either submersible or not,—continuous, or with small openings, to allow the passage of flood-waters, according to the local peculiarities of the river to be acted upon. A knowledge of the modifications to be introduced in the application of these general rules constitutes, in fact, nearly the whole merit of an Engineer.

32. Continuous banks are executed in many different ways, according to the nature of the soil, the course of the river, and, above all, according to the nature of the materials to be met with the most readily, and at the cheapest rate. On the Continent they are executed sometimes in rough blocks of stone or concrete; of fascines, or of panniers in osier, filled in with gravel or rubble-stone; or lastly, by a combination of the above methods, which answers very well for the immersed parts of the bank, when the portions out of water are dressed off to a regular slope, and planted, or paved with a dry stone pitching, laid in either regular or irregular courses.

Embankment Walls.

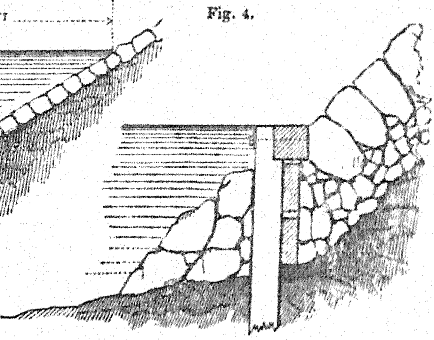
On the banks of the Loire the slopes are protected by means of stone pitching, which is remarkable for the perfection of its execution and its comparatively feeble thickness. They are generally inclined in the proportion of $1\frac{1}{2}$ of base to 1 in height. A bed of gravel is placed behind them, and the foundations are merely formed by an excavation or trough dug in the sand below the level of the mean summer waters, subsequently filled in with rough rubble masonry. At times, however, it has been found necessary to introduce gauge-piles with longitudinal wales, as shewn in figs. 3 and 4.

Fig. 3.



Embankment on the Loire, near Amboise.

Fig. 4.



Foot of the same on a larger scale.

Occasionally also the inclination of the slopes is increased to 2 of base to 1 in height. The thickness at the top is made between 8 inches and 1 foot. The augmentation in the thickness is usually about 3 inches for every 3 feet 4 inches in height.

Timber Walls.

33. A timber walling often suffices for the protection of a bank of a river, and affords means of diminishing the width of the stream. An example may be taken from the artificial channel made in the Port of Lorient. But it may be observed that the gauge-piles in such works require to be driven to very considerable depths;

and that if the waters have what is technically called any scour, the solidity of banks thus made is more than questionable.

Fig. 5.

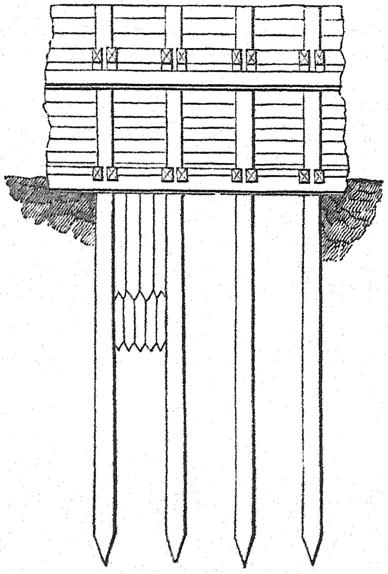
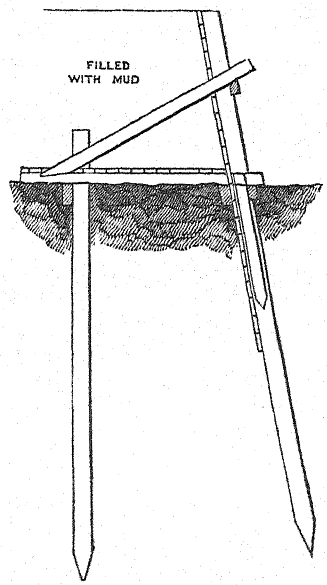


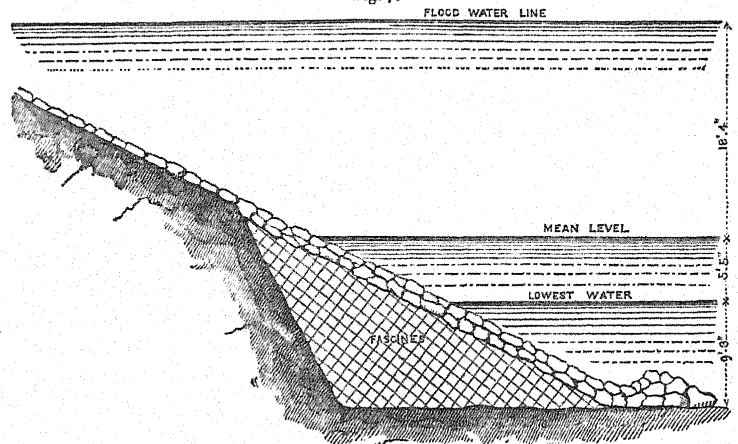
Fig. 6.



Mixed System on the Rhine.

34. On the banks of the Rhine and in Holland, the high price of stone, combined with the unlimited supply of gravel and aquatic trees, have led the French, German,

Fig. 7.



Mixed System used on the Rhine.

and Dutch engineers to substitute either a mixed system of fascines paved with stone, or what they call 'tunages,' for those employed in the countries where stone is abundant. Works for the defence of the banks, or for the regulation of the waterway, executed in this manner do not, it is true, last very long; but their

relative duration is sufficient in rivers carrying much suspended matter, for they give rise to depositions which eventually serve to effect the object intended in a more permanent way.

Tunages. 35. The tunages upon the Rhine consist, in the portions submerged below the level of the low summer waters, in floating layers of fascines, which are firmly fixed in the bank, and sunk by being loaded with gravel or rubble-stone. These layers of fascines are fastened, either to the bed of the river, or to the subjacent layers, by means of strong pickets. The work is so divided that the beds of fascines float at their extremity towards the river, so as to leave toothings, in case it becomes necessary to advance the work further into the waterway or thalweg. The flexibility of this kind of carpet also enables it to adapt itself with more facility to the different forms of the bed. Great rapidity of execution is necessary whenever the tunages are used, in order to avoid the dangerous effects of the scour of the waters under the floating extremities of the fascines.

Fig. 8.

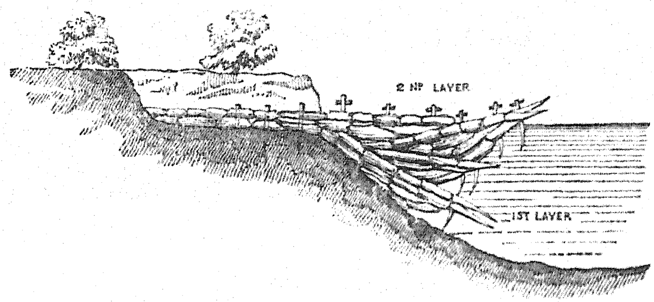
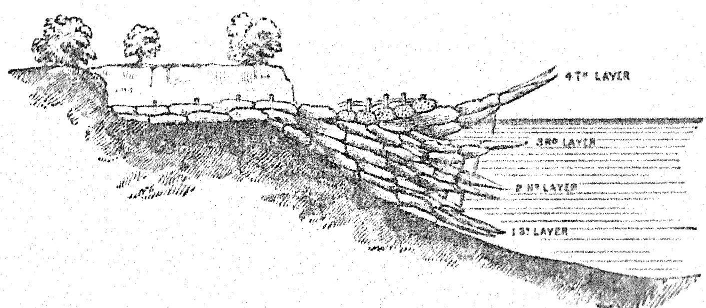


Fig. 9.

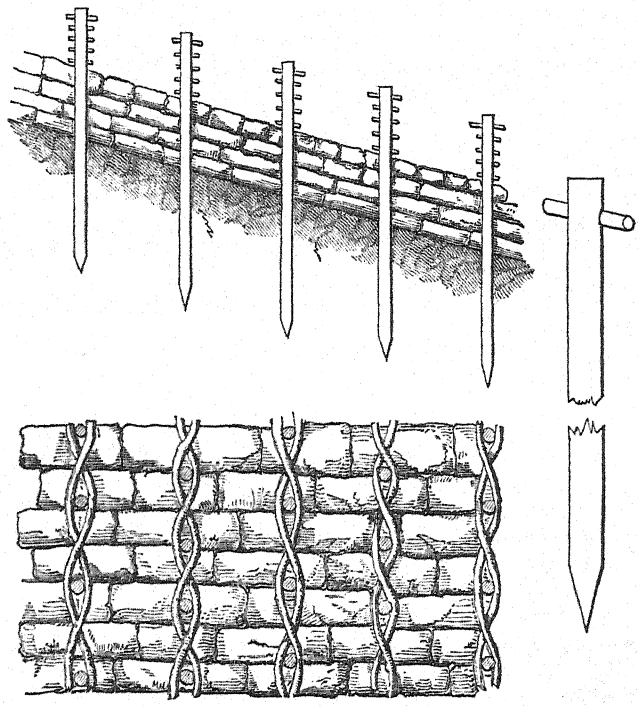


In Holland, when the banks of a river are attacked by the current, immense platforms are constructed of such tunages, which are floated to the positions they are intended to occupy, and there sunk. Such a mode of proceeding is practicable in a country where the waters may all be said to be sluggish, but when the current attains any degree of velocity it ceases to be of any practical use.

Clayonnages. 36. The original banks of a river, or any embankment formed for the contraction of its channel, are sometimes defended by what are called 'clayonnages.' This method consists in covering the surface to be protected by fascines laid transversely to the direction of the current in three or four rows. Strong pickets are driven through them, and are allowed to project about 18 inches above the top. Withes are then passed over the projecting heads of the pickets, and serve to form a kind of frame-

work on which stones and gravel are laid, to maintain the fascines in place, and to stop any matters which may be in suspension in the waters. The durability of such works is not great, nor should they be resorted to in positions where stone defence-walls can be erected with due regard to economy.

Fig. 10.



Clayonnage used in Holland, and upon the Banks of the Rhine in France and Germany.

37. In our own country the use of fascines is almost exclusively confined to the Corps of Royal Engineers. The usually adopted systems of protecting the banks of rivers are limited to modifications of dry stone walling or of timber revetments. On the banks of the Thames some very extensive works have been executed for the protection of the low lands, especially below the bridges; but they may be said to be more remarkable for their magnitude than for the skill or economy of their execution. In fact, the extreme regularity of the course of our rivers has so simplified the difficulties connected with works intended to maintain them, that very little attention has been paid to the subject by English Engineers.

38. In many rivers the banks are protected by a series of spurs without return ends, projecting into the stream, and attached solidly to the bank. It was formerly considered that such spurs were more economical than a continuous embankment. In some instances they protect a length on the upper side of double their projection, and on the lower of three times the same length; but they have been found to produce sinuosities in the course of the stream, and to determine strong corrosive actions on the down-stream side; moreover, the heads of the spurs themselves are much exposed to the undermining action of the waters. The dangers of the use of spurs are most strongly developed during floods. In ordinary states of the river,

the water which passes into the angles formed by the spur becomes stagnant, or it turns slowly, especially on the up-stream side, and allows a deposition to take place; but when extraordinary floods occur, and the velocity of the stream becomes very great, the rotary motion of the water not unfrequently produces a whirlpool which injures the bank and the works of the spurs themselves. The spurs, in fact, give rise to a destructive action more powerful than the one they were intended to guard against.

New Channels, Cuts, and Dredging.

New Channels and Cuts.

39. In certain rivers whose section is very great, and which are liable to great floods, —whose beds may be said to possess great mobility, and whose central portions are often occupied by islands,—the navigable channel is likely to pass from one bank to the other by traversing the intervals between the islands, and it has been attempted to rectify the bed by creating new channels across the latter.

The practical results obtained by the Engineers of the Rhine (a river which is in all respects worthy to be taken as a model, both from the difficulties it presents, and the skill employed in overcoming them) have led to the establishment of the following rules:

1st. The new channels should be as deep as possible.

2ndly. They must be connected with the old channel by curves of considerable radius.

3rdly. They must not be opened to receive the waters of the river until the down-stream end of the ancient pass has been completely closed. It has been found impracticable to divert the waters into the new channel unless this be done, because it is impossible to throw out the new cut to a depth inferior to that of the old channel.

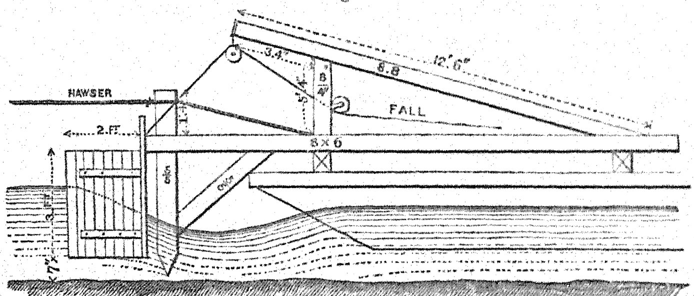
4thly. The beds of the new cuts must be cleared of all trees, reeds, or aquatic plants, in the zone in which it is intended that the river should flow.

It has been found that cuts having only between 17 and 30 feet at the bottom, or floor-line, were sufficient for the Rhine, notwithstanding its immense volume. The waters directed into the new cuts do, in fact, very rapidly both deepen and enlarge the channel to the extent necessary to insure the full discharge of the stream.

Dredging.

40. An economical manner of removing the materials of the bed of a river consists in the application of moveable dams attached to a boat. These dams offer a resistance to the flow of the water; and, according to the greater or less depression given to them, they either divert the whole effort of the stream against any particular

Fig. 11.



object, or, by simply contracting the waterway, they augment its velocity, especially at the bottom. This mode of dredging cannot be applied if there be any necessity

for the removal of the materials disturbed. It evidently only acts by displacing them, leaving them free to be deposited elsewhere. Wherever applicable, this system has been found to diminish the expense by about $\frac{9}{10}$ths.

The machine shewn in fig. 11 was employed on the Garonne, in which river it removed about 60 yards per day of sand and clay, at an expense of about $2\frac{1}{4}d.$ per yard cube.

41. In the United States, rocks in the beds of rivers are often removed by means of a series of stampers, set in motion by the waters of the river acting upon wheels attached to boats or any other temporary staging. Sometimes it is necessary to employ the diving-bell, and to blow up impediments to the navigation with gunpowder. At others, and especially when it is desirable to remove entirely all the materials loosened from the bed of the river, the dredging-boat, moved by steam power, is employed.

Natural Bars.

42. Before quitting this subject, it is necessary to notice an interesting fact as regards the beds of rivers. In many cases, particularly in those where the bed is composed of gravel, natural bars form, as it were, of their own accord: if removed, they are re-formed with great rapidity, and appear to result from the form of the bed, which gives rise, in these precise localities, to a sort of slackwater favourable to the settling of the gravel. Advantage should be taken of the indications thus given; for if it be desired to erect a dam or barrage, the positions of these natural bars will be found to be the most advantageous, and the direction they take with the current will also be the one most likely to insure the solidity of the construction.

General Considerations upon Works for the Establishment or the Amelioration of the Navigation in Rivers.

Economical considerations.

43. The solution of the questions connected with the establishment of river navigation is attended with so many difficulties both technical and commercial, whose importance varies with almost every separate case, that it is impossible to lay down any invariable rules to guide the conduct of an Engineer. Local circumstances influence to so great an extent the favourable economical results of such work, that every river requires to be examined, as it were, upon its own capabilities.

When the navigation takes place downwards only, and there is a sufficient depth of water, and when the flow of the water is alone the moving power, the danger to be obviated can solely arise from the too great rapidity of the current. If it be desired to render the river able to float larger boats, its depth can only be augmented by retarding the velocity. The question to be examined before undertaking works to effect this, is whether it be more economical to employ large boats with a longer total passage, or small boats travelling with greater rapidity.

If the navigation take place upwards, works which would retard the velocity of the stream produce not only a great saving in the motive power, but also enable larger vessels to be employed: the question in this case is simply whether the navigation is sufficiently active to justify the expense incurred. But if the navigation takes place in both directions and in variable proportions, the solutions admit of an endless variety.

44. The first considerations which arise, when we examine the necessity for improving a river, are,—shall the navigation be kept in the old channel?—shall a new one be opened, either with running waters, or with still waters as in a canal?—on which bank shall the navigation be maintained? These considerations are moreover complicated by the nature of the country on the banks of the river, the rights of the proprietors, the occasional presence of mills, and even by questions of military de-

fence. Finally, we may meet with physical impossibilities; or, at least, the outlay may be so enormous as not to warrant any hope of success.

Scientific data required.

Before proceeding to lay down any project for the improvement of a river, a general plan must be made of the main stream and of all its affluents. Longitudinal and transverse profiles, and levels of the bed, the banks, and the land immediately upon them, must be taken. Careful observations must be made upon the heights of the lowest waters, the mean, and flood streams, taking care that they be averaged over the greatest possible number of years; and the volume of the river must be gauged in all the above states. The nature of the matters held in suspension, the tendency of the river to scour, or to deposit, and the nature of the bed, are also points of vital importance. The form, and tonnage, of the boats in use upon the river to be improved, or upon any other river with which it communicates, must also be ascertained. The capabilities of the surrounding country for the provision of materials necessary for construction will also require to be noted.

Formulæ of Volume of a Stream.

The formulæ announced by De Prony, and verified by Eytelwein upon some large rivers, are of great service in determining the volume of a water-course. Leaving out of account the form of the banks, they are

$$V = l.h\,u, \quad u = -0{\cdot}07 + \sqrt{0{\cdot}005 + 3233\,\frac{l\,h}{l + 2\,h}\,i},$$

in which V = the volume per second; l = the width of the bed; h = the mean depth; u = the mean velocity per second, and i = the fall.

In rivers whose width is great in proportion to the depth, the value of u may be safely taken as being

$$u = -\,0{\cdot}07 + \sqrt{0{\cdot}005 + 3233\,i\,\frac{l}{l + 2}},$$

or even when the width exceeds 130 feet,

$$u = -\,0{\cdot}07 + \sqrt{0{\cdot}005 + 3233\,i}.$$

More detailed information upon the application of these formulæ will be found in the works of De Prony, Coriolis, and Gauthier, or in the 'Annales des Ponts et Chaussées,' 1835–6.

Effects of Bed.

45. One of the first obstacles to the navigation arises from the narrowness of the stream, either in the straight parts of its course, or in the curves. If it be attempted to remove this obstacle by excavating the sides, we are likely to diminish the velocity, and also, very probably, the depth. Moreover, if the river hold much extraneous matter in suspension, the depositions which will take place in the still waters will probably cause the banks to be re-formed, unless the channel be kept open by continual dredging.

46. Bends in rivers affect the navigation injuriously in two ways. Firstly, they diminish the width practicable for boats; and secondly, they augment the length of the traject. By opening a new passage between the extreme points, the velocity is increased, and simultaneously the depth is diminished. It often happens, if the banks be easily corroded, that at the time of floods the river re-opens its original channel; an accident which occurred on the Oise above Compiegne.

Modes of remedying Defects.

If the bend be of sufficient importance, the best method of obviating it is to construct a lateral canal with locks. Of course it becomes a matter of calculation whether the economical returns of such works compensate for the outlay.

If the nature of the bed or the velocity of the stream be the principal obstacle to the navigation, these may be obviated as follows. Firstly, either by lengthening the course of the river, by widening it, or by deepening it; or by a combination of

two or more of the above methods. Secondly, by establishing transverse dams to retain the water, in a series of ponds of still water,* between which communications are established by locks, sluices, or flashing gates, to be subsequently described.

When the want of depth is the principal obstacle, it is sometimes obviated by contracting the channel, either by transverse dikes, or spurs, fixed to one or both banks, or by longitudinal dikes, either single or double. When rivers are divided into numerous branches by islands in mid-channel, the dikes are established in such a manner as to close up the smaller branches, and to connect the islands with one another. Some very important works of this description have been executed on the Loire, between Orleans and Nantes; and also upon the Seine, between Paris and Rouen. These will be described in detail; but it may be here observed, that the results confirm the assertion, "that the only certain mode of deepening a river is by the establishment of continuous longitudinal embankments."

Height of Embankments.

47. The height chosen for the crown of embankments is a subject which requires mature consideration; for upon it depends, to a great extent, the action of the upper floods, and the scouring action of the river. The dikes or dams of the Loire, of the Rhine, and of the Po, when they are executed, as in the latter, at a distance from the bed of the river, do not produce any danger from the causes here mentioned. They are, in fact, only intended to resist the floods, which on extraordinary occasions would otherwise overflow the fertile lands at the back of the embankments. It has been found advisable in practice never to allow the crown of the embankments erected for the purpose of diminishing the channel to exceed the level of the mean waters; whilst they only exceed that of the low waters by about 2 feet, and are covered by the floods.

48. The following simple rules suffice for ordinary cases, and they give results which are tolerably accurate. 1st. The velocities vary in the inverse ratio of the cube roots of the widths. 2ndly. The cubes of the heights are in the inverse ratio of the widths of the beds. In the United States, the principle adopted to regulate the dimensions of the narrowed pass is, to make its capacity equal to that of the ancient bed. As much as possible it is requisite to preserve the natural waterway; and if it be necessary to displace it at all, to direct it, in preference, to the bank or portion of the channel most likely to yield to the deepening action of the waters.

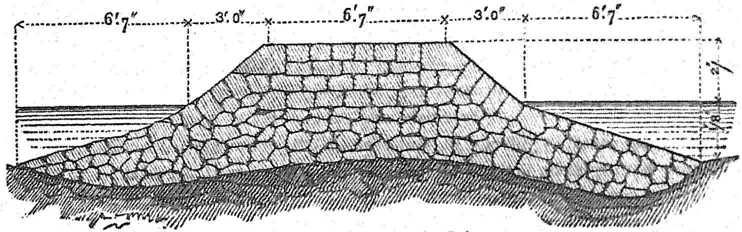
Dikes or Dams in Tidal Portions of Rivers.

49. Longitudinal dikes appear to be indisputably the form most fitted for the tida portions of rivers, inasmuch as they allow the tidal waters to spread with greater regularity. On the Clyde, the Dee, and the Ribble, it was attempted to deepen the waterway by means of transverse spurs, or jetties; but the experience of the best Engineers has led to the substitution of the longitudinal dikes. These are, in the cases referred to, executed in rubble-stone, and are usually from 3 to 5 feet above low-water mark. When covered by the tide, their position is indicated by beacons placed at regular intervals. Some very interesting information upon the subject of the improvement of the tidal portions of rivers is to be found in a short work by D. Stevenson, Esq., published in 1849. The Report made by Messrs. De Prony and Sganzin, in the year 1806, upon the works projected by the order of Napoleon, for the restoration of the Port of Venice, contains also very valuable observations upon the best method of improving tidal rivers.

The materials employed in the execution of these jetties, spurs, or dikes vary with the nature of the country in which they are situated. It is always a very difficult operation to close any waterway, especially when the bed is easily removed. If the dam be executed by commencing from the two sides, the passage becomes

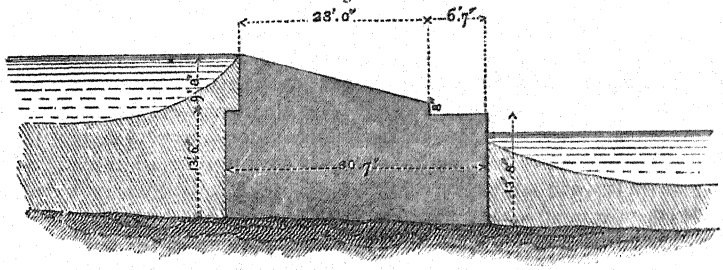
* As on the Rideau Canal, Upper Canada.

Fig. 12.



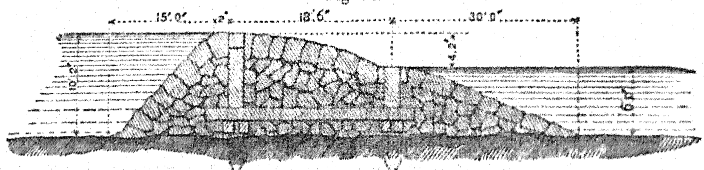
Dike at Orleans, on the Loire.

Fig 13.



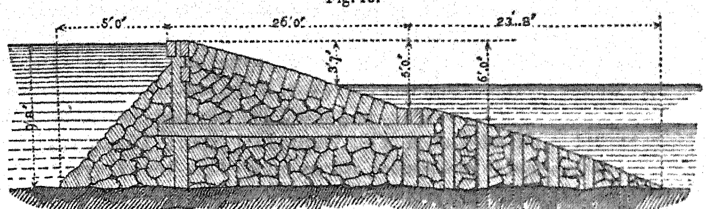
Dike on the Tarn at Fontvilaine.

Fig. 14.



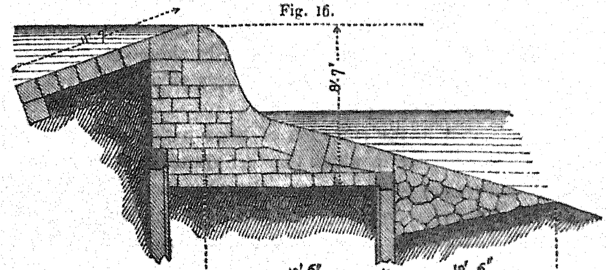
Dike on the Doux at Moulin l'Hermite.

Fig. 15.



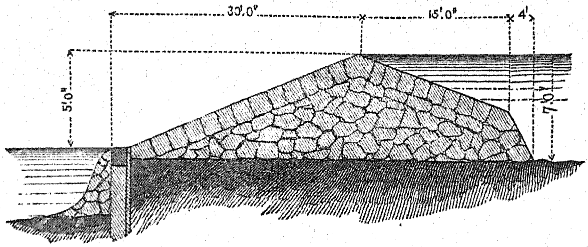
Dike on the Oise at Pontoise.

Fig. 16.



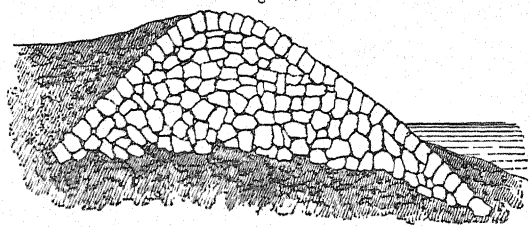
Dike on the Weaver, by Telford.

Fig. 17.



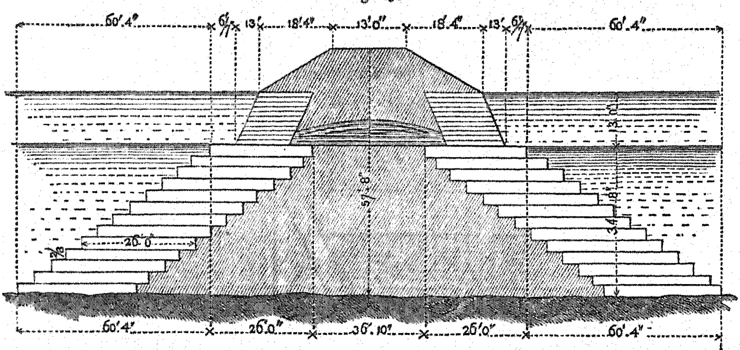
Dike on the Carron, by Smeaton.

Fig. 18.



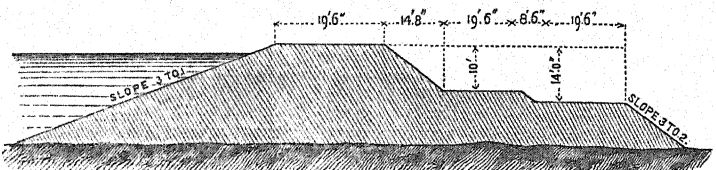
Dike on the Ribble, by D. Stevenson.

Fig. 19.



Dikes to close small Branches of the Lower Rhine, in Holland.

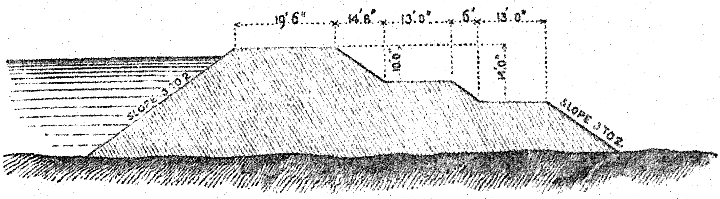
Fig. 20.



Dike of the Po, 'en froldi,' or close upon the waterway.

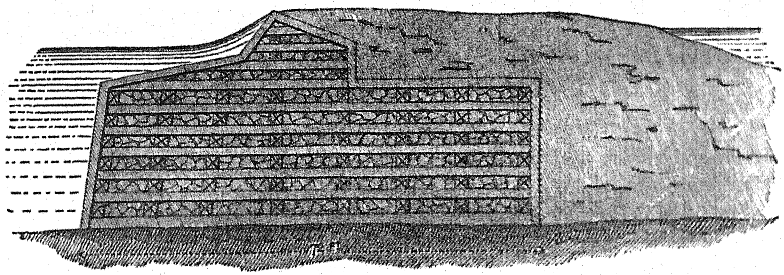
contracted, the speed of the current augments, and necessarily the bed becomes deepened. If, on the contrary, the dam be executed in horizontal layers, the waters retained flow over the top and produce a cascade which is likely to overthrow the structure. It appears, however, preferable to adopt this latter course, wherever it is feasible. In any case it is requisite to execute these works at seasons of the year when the waters are lowest.

Fig. 21.



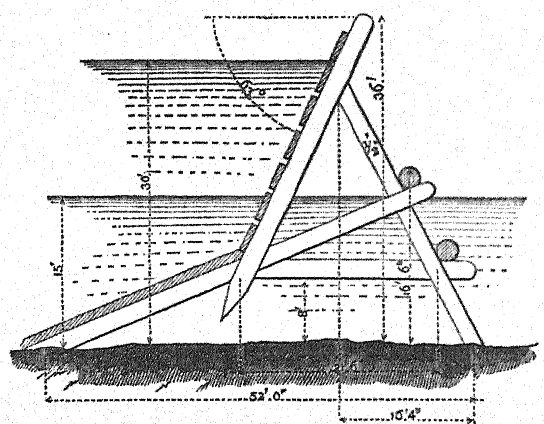
Dike of the Po, 'en golene,' from 1 to 3 miles from the river.

Fig. 22.



Dam across the Hudson, near Albany, U. S.

Fig. 23.



Magistrini's Temporary Wooden Defence-walls, applied upon the banks of the upper Po, in Piedmont. They were executed in round timber, planked to the first bend with close planking, and the boards above were laid with a space between.

Whatever system be adopted for such river-works, it is indispensably necessary that any defect be remedied at once. Constant inspection, great care, and continual labour, are the only means by which the banks of rivers can be maintained. No short-sighted notions of economy should be allowed to interfere with the organization of an efficient system of maintenance.

Dams or Barrages in Rivers.

50. When rivers bring down small volumes of water, the simplest method of rendering them navigable is by the erection of dams or barrages across their beds, thus creating a series of ponds. The communication between these ponds may be effected by sluices, as before observed in the case of floatable rivers, or by locks, or even through a pass left constantly open. These last are, however, simply transverse jetties, which narrow the bed of the river.

Dams may be either fixed in their whole height, or they may be moveable in such a manner as to leave a free passage for the waters in time of floods.

of Flow The object of continuous dams is to cause the waters to rise on their up-side, so as to obtain a sufficient depth for the purposes of the navigation. Their result is to diminish the depth of the waters below, in consequence of the additional velocity acquired by the fall over the crown of the dam. The depth of water upon the crown depends upon the length of the dam. M. Castel's formula for ascertaining it (which is generally adopted by Engineers in calculations of this nature) is

$$x = 0{\cdot}64 \sqrt[3]{\left(\frac{Q}{L}\right)^2},$$

in which x is the height sought; Q, the discharge per second; and L, the length of the dike or bank.

51. Although the dam produces the effect of retarding or heaping up the waters, it is not immediately upon it that they attain the greatest depth, but at a certain distance above. The surface of the fluid assumes a convex form before arriving at the dam, the curve of which commences at a very considerable distance. MM. Guilhem and D'Aubuisson consider the curve to be a portion of a hyperbola whose summit is above the dam before the waters begin to fall, and whose asymptote is the line of the natural mean fall of the waters before the establishment of the dam. The equation of this curve would be

$$\left(\frac{y + p\,x}{H}\right)^3 - \frac{p\,x}{H} = \frac{1}{1 + \frac{4}{g}\,H\,\frac{(p\,x)^6}{H}},$$

in which x is the horizontal distance of any point in the curve to the dam; y is the height to which the waters are heaped up at that point above the original level; H, the greatest height to which they are raised; p, the fall of the bed of the river, in this case supposed to be straight.

It is usual to place the dams at sufficient distances from one another to allow the level of the waters thus kept back to meet the level resulting from the natural fall of the bed. The crown is kept at about from 8 inches to 1 foot below the height calculated for the augmented depth. The formula for calculating more exactly the distance of the extreme point of the difference of level created by the dam is (supposing the coefficient of contraction to be 0·70)

$$q = 1{\cdot}86\,l\,d\,\sqrt{d + 0{\cdot}08\,V^2},$$

in which q is the quantity of water discharged per second; l, the width of the dam;

d, the distance of the extreme point sought; V, the mean velocity of the up-stream. M. D'Aubuisson prefers the formula

$$q = m\tfrac{2}{3}\sqrt{2g}\,.\,lh\sqrt{h},$$

in which m is the coefficient of contraction; h, the difference of height between the crown of the dam and the sheet of nearly stagnant water which is found above it.

Different Systems of Dams.

52. There are two methods of establishing dams in rivers; either with small falls often repeated, or at considerable distances asunder with great falls. The latter system has the advantage of causing less interruption to the navigation, and of losing less time in the passage of the locks; but it is accompanied by great increase in the expense; for as the weight of water acting upon any construction increases in the ratio of the squares of its height, the strength and consequently the expense of the works must increase in the same ratio. The height usually adopted is rarely above 6 feet 6 inches: when there are no locks for the passage of the boats, the height is not more than from 3 feet 3 inches to 4 feet 3 inches. The nature of the bed of a river also becomes an important element in the solution of the question as to the position of the dams. It is evidently essential that they be placed in positions where the fall of the cataract is not likely to undermine them.

In order to augment the width of the section, and thus to diminish the velocity of the stream falling over a dam, it is frequently made with an inclination towards the stream. But as the direction of the water flowing over is always normal to the line of the crown of the dam, it is likely to produce corrosions upon the banks on the down-side. A safer way of augmenting the section is to dispose the dam in a convex form to the up-stream; or, if the labour upon the masonry of this arched shape be too great, a *chevron brisé* may be substituted, observing that the salient angle is presented to the stream. Both of these forms have, however, the disadvantage of contracting the waterway, and of facilitating the deposition of silt in the angles of junction with the locks or sluices.

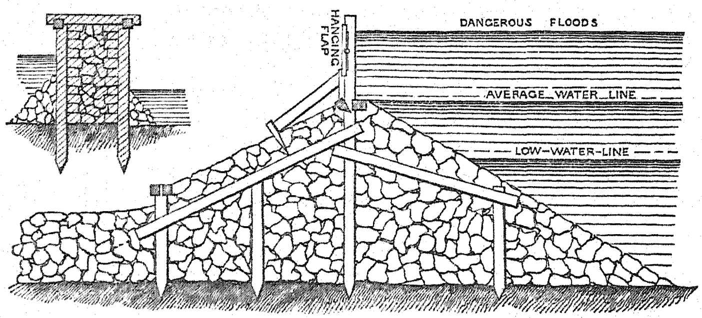
Construction of Dams.

53. Dams are made either with vertical faces or with slopes. The vertical face presents the advantage of immediately checking the velocity of the current by the effects of the cataract; but in this case other works are necessary, to secure the foundation. If the down-side be made with a slope, the excavating action of the water is diminished, but the mass of the construction is augmented. Local considerations of economy must guide the Engineer in the choice of the form to be adopted; the nature of the bed also forms a very important object of consideration in the determination of such questions.

An example of the mode of constructing the dams used in the United States is given in figure 22, page 250. They are made in sections about 20 feet long, as in the example given, of timbers 20 inches square, notched down upon one another 3 inches. These sections were gradually sunk into their positions, well fastened together, loaded and backed up with stones and gravel. Six-inch planking is laid on the upper surfaces. This dam has an inclination of 45° to the stream, and measures 72 feet across at the foot. The total length is 1600 feet. A portion of it is executed in rubble, for a length of 270 feet, the width at the top being 12 feet, and at the bottom 150 feet.

Dams are sometimes executed in vertical cases of wood-work, similar to coffer-dams, and consisting of main and sheet piling, filled in with rubble, the foot of the down-side being protected by loose stone left to find its natural slope. Again, at other times an open frame-work of carpentry is driven into the ground, which is filled in also with rubble, but dressed off to a regular slope, which is much greater on the down than on the up side.

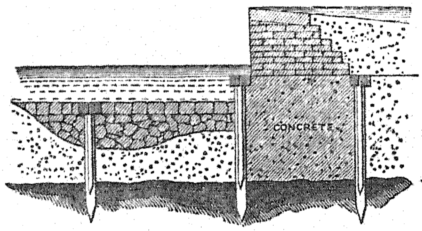
Fig. 24.



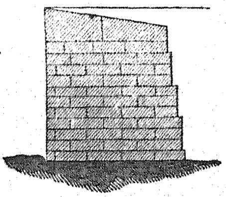
Stone Dam on the Lesser Saone River.

54. The crown of a dam must always be made with an inclination towards the up-stream, in order to facilitate the afflux of the sheets of the fluid towards the extreme edge, thus—

Figs. 25 and 26.



Dam at Coly.



Dam upon the Blavet.

Another very necessary precaution to be observed in constructing the dams of timber-work is to prevent any of the beams from traversing the whole structure, as they would act as pipes to allow the water to pass through.

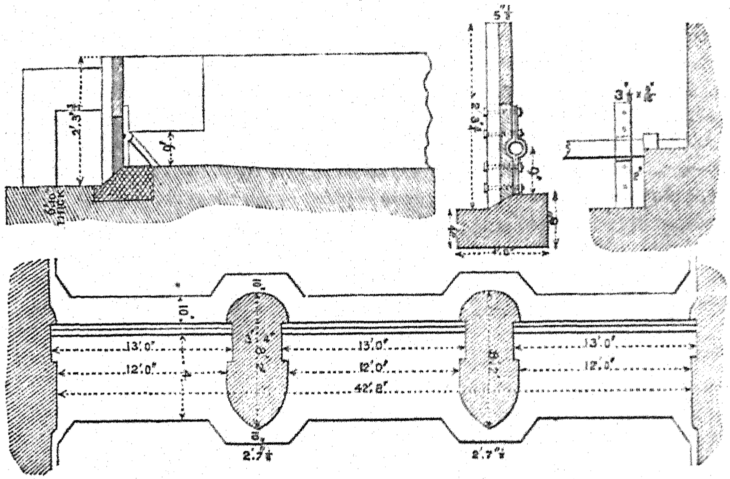
The platform on the down-side should be made of a length equal to three times the height of the dam, when this is vertical. It is advisable to strengthen the part upon which the water falls directly, and, if possible, to interpose some elastic substance, such for instance as a bed of fascines. The lower extremity of the platform must be guarded by a range of close piling.

In some rivers the dams are made with openings, to which gates, or other methods of closing, are applied; so that they are shut during the dry seasons, and open when the waters rise. These dams present a series of piers and openings in the river precisely analogous to the piers of bridges, and they require the same methods of construction and defence those works would. The dimension of the openings is regulated by the mode of closing, and it varies from 13 to 26, or even to 48 feet, according to the size of the boats or the violence of the floods.

55. On the Marne, the Yonne, and the Aude, the system of closing consists in a set of moveable blades turning on a pivot at the bottom, and bearing against a bar at the top, which itself is moveable. A bolt being drawn, the weight of the water forces the top bar to swing round, and the blades then fall to the bottom, leaving the pass clear. In other cases the blades are horizontal, and shut against a vertical locking-bar, or the blades are converted into a solid door or gate. When the

openings are not intended for the purposes of navigation, they are closed by vanes set in motion by crabs or winches, or by horizontal flaps at different heights. Sally-gates have been used, but they require too great an effort to open them against the stream. Turning-gates upon vertical hinges have also been tried, but they are objectionable, in the first place, because they hinder the navigation; and in the second, because they require an extra thickness of very expensive masonry. In cases where the height of the water kept back has been but insignificant, it has been found that the use of dams which open and shut simply by the weight of the water acting upon them has answered tolerably well. Their application is, however, very

Fig. 27.



Self-acting Dam at Pont de la Pradès, at Riom.

limited, because when the height becomes important, the construction of these works becomes proportionally complicated and expensive; they are also liable to be easily put out of order, and are difficult to repair.

The width of the sluices left for the flood-waters or for floating the wood-rafts, upon the Continent, varies from 10 to 26 feet. In order to economize time, and, to a certain extent, the works necessary to the efficient service of these sluices, it is generally found to be advantageous to place them at one of the extremities of the dam. When locks are constructed, the sluices are placed close to them for the same reasons. The floor of the pass of the sluice is kept at the same level as the bed of the upper portion of the river, and is joined by a regular fall with that of the lower, so that in case of necessity the sluice may be used for the passage of boats. When the bed of the river is soft, the floor of the sluice must be protected by a platform.

The dam indicated in p. 253, as being used upon the Lesser Saone, is a mixed construction, one part being fixed, the other moveable. The fixed part varies in height from 2 feet to 4 feet above the low waters; the moveable parts, which consist of a series of leaves turning upon horizontal pivots, vary in height from 1 foot 4 inches to 4 feet 6 inches. When the floods attain a dangerous degree of elevation, they overbalance the moveable parts, which fall flat, and thus allow the surplus water to escape.

Moveable Dams. 56. M. Poirée, Engineer in Chief of the navigation of the Seine, introduced upon the Yonne, and subsequently upon the Seine itself, a kind of moveable dam whose application is spreading very rapidly in France. It consists in the use of a series of

metal frames, fastened together at the top, so as to be laid flat on the bed of the river by turning on their bases as hinges. The frames are let into a groove sunk in the floor of the dam, in such a manner that the frames, when laid flat, do not project above the bed of the stream. The frames are maintained in their vertical position by a moveable bar which fits down upon them, and serves to keep the blades closing the waterway in their positions at the top. At the bottom, the blades fit into a groove made in the floor of the passage. They are of wood, from 4 to 5 inches wide, and are pressed against the top bar by the weight of the water. The height of the frames may vary from 4 to 10 feet; their distance apart is made equal to their height, with a small allowance for play. These dams are exceedingly economical, and they present the advantage of being susceptible of leaving the whole or any portion of the water clear, as occasion may require, whilst they are equally effective in closing it entirely. M. Poirée estimated the expense of such dams at about £40 per yard run.

57. Whatever be the nature of the dam employed, some means are required to enable the navigation to pass from one level to the other. For floatable rivers, sluices suffice, which must be made of such dimensions as to be able to pass any raft of the ordinary construction of the country. The wing-walls of the passage must be continued down the stream, to guide the boats, and more particularly to diminish the curvilinear fall of the water. The danger attending the difference of level above and below the dam induces Engineers in practice to recommend that the sluices be opened about a quarter of an hour before boats or rafts are to be passed, although, by so doing, the level of the water in the upper bay is inconveniently depressed. For the facility of guiding boats through the sluices, it is desirable that they be placed as near the towing-path as possible.

Locks for River Navigation.

Locks, &c. for Rivers.

58. The use of sluices is accompanied with so much danger and difficulty, that in all cases where the navigation assumes any importance, locks are substituted for them. Locks may be called hydraulic machines, by means of which heavy cumbrous bodies are raised from one level to another, or *vice versâ*. They consist of a basin of variable surface, which is closed by gates at each end. The floor of the lock is on a level with the bed of the lower part of the river to be communicated with. The crown is on a level with the upper. When a boat is to be passed from the one to the other, it then becomes necessary to alter the level of the water in the intermediate basin, so as to bring it to that of the respective bays. The boats are thus passed from one to the other without the risk of shocks, and with the least possible expense of water.

59. River locks may be placed in the bed of a river or in a short branch made parallel to the main bank. When a river divides into several branches naturally, it is usual to place the dam at the head of one of them and the lock at the end of the other, so that the intermediate portion of the original bed of the river becomes converted into a basin. The reasons for which this particular arrangement is adopted are, because it is easier to construct the lock in such positions, by merely diverting the waters of the river in the mean time into the secondary branch; and because the still water thus created above and below the locks, free from the agitation of the cascade over the dam, is found to be highly advantageous to the navigation. Moreover, the lock itself in such positions is less likely to be affected by gravel or mud, especially if guard-gates are placed at the entry of the basin thus formed.

If, however, the form of the river be such as to render it indispensable to place the lock in the bed, it must be placed at one extremity of the dam, so that the side wall

Fig. 28.

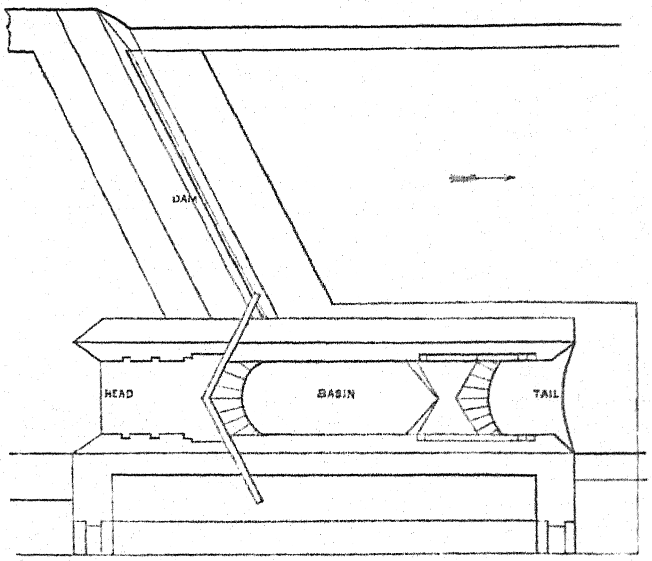
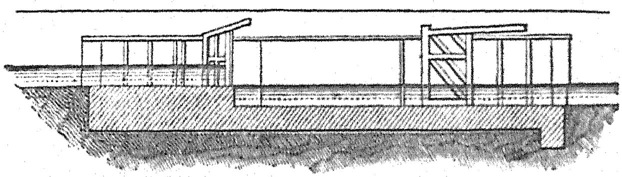


Fig. 29.



forms also the retaining wall of the towing-path. The tail-walls must be prolonged into the stream, so as to remove the boats from the agitation produced by the waters falling over the dam; and by this disposition the wing-walls, upon a considerable portion of their length, are removed from the charge of the water in the upper level or pond.

60. A very important question to be decided in the construction of river locks is whether they should be submersible or not. In the former case, great danger is incurred from the effects of the waters acting upon the embankments by the side of the wing-walls; and it is necessary, in order to guard against this danger, that they be covered with a stone paving laid on a bed of concrete. The gates should also be opened in order to prevent any kind of cataract. Where the locks are kept entirely out of the water, they offer the serious impediment to the navigation of requiring that the towing-paths be elevated, sometimes to a very inconvenient degree; and they also require long inclines to reach the level part of the embankments. It may be said, however, that when floods attain any degree of elevation, such as to render it necessary to keep the top of the locks inconveniently high, the navigation is entirely suspended: all the advantages are therefore in favour of submersible locks for river navigation.

If the locks be insubmersible, it is desirable, to facilitate the working in ordinary states of the river, that the tail-gate especially be made in two parts; the upper part to shut against a rabbet in the lower one.

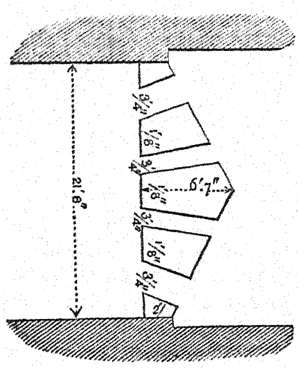
With the exception of these cases, the locks are closed with double sally-gates, the difference of level of water being obviated by means of vanes, or water-ducts, as explained in the following Section on Canals. It is advisable in all such works to leave grooves in the wing-walls to receive a temporary dam, in case repairs are found necessary.

The same perfection is not required for a river lock which is found necessary for canals, as they are hardly ever liable to be short of water. Still there is so important a loss of time resulting from the infiltration through the wing-walls, that it has been found to be advisable to have them well built. The same motive of economy of time has led in some cases to the placing of a supplementary pair of gates, in order that when small boats have to pass the lock, it may not be required to fill the whole length of the basin. When the navigation is very active, it may occasionally be necessary to make more than one lock: in that case it would be better to make them side by side, as the middle wing-wall would serve for the two. At all times it is necessary to pay particular attention to the size of the boats frequenting the river or its affluents, for that must regulate the dimensions of the locks.

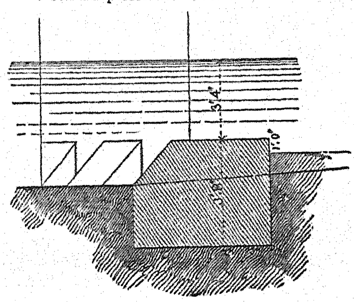
61. It has occasionally been found advisable to establish sluices in the lock-gates, for the purpose of scouring out the mud, especially in river locks. The action of these is, however, very imperfect when the cascade-wall is high enough to prevent the water from sweeping the bottom of the basin. This inconvenience has been remedied in some cases by making the bottom line in a regular incline from the entry of the lock to the tail-gate. In the United States, the cascade-wall is often thus suppressed, and in the middle of the basin a grating is fixed, to catch any aquatic plants likely to interfere with the opening of the lower gates. On the Loire an intermediate system has been followed, by which the height of the cascade-wall has been diminished without being entirely suppressed: in fact, it has been found that the extra height thus given to the upper gates rendered their action slow and difficult.

62. Great precautions are indispensably necessary as regards the foundations of river locks, to protect them from the extreme force of the excavating powers of the stream. Even when the bed of the river is of a resisting character, it is advisable to let the foundations into the rock about 3 or 4 feet. If the bed be likely to yield, a long platform must be executed both above and below the lock, so as to form there at least a solid bed. If the work be upon piles, the extremities must be protected by a continuous range of close piling, and any projecting part beyond the line of the first set-off must be carefully paved. In making the floor it must be borne in mind that the weight of the water of the upper level acts upon it to blow it up; the

Fig. 30.



Lock-sill perforated to form a Sluice.



dimensions must therefore be sufficient to resist this action. It is always preferable to execute the floor as an invert.

In the United States many inclined planes have been executed to carry vessels over considerable falls. Indeed, the difficulties attending the establishment of locks in rivers are so great, that they have led Engineers to prefer the construction of lateral canals, whose works, especially in the intermediate portions, are much more easy of execution, and also much less exposed to accidents from floods. Details of the execution of lock-gates and the other parts of such constructions will be found in the succeeding pages.

SECTION II.—CANALS.

1. The dangers alluded to in the first portion of this article as attendant upon the construction of works in the bed of rivers, and the constant interruptions to which the navigation is exposed from the various conditions of their course, sufficiently explain the preference accorded to lateral canals. These canals, however, only serve to regulate the navigation in the direction, and, generally speaking, in the hydrographical basin of the existing streams. Another very important class of canals is that for the purpose of forming a navigable communication between rivers flowing perhaps in opposite directions, and to overcome the difficulties arising from the interposition of the mountain chains whence the rivers take their source. Such canals, then, have forcedly a summit level, and lock down in both directions, in order to carry the navigation over the differences of level.

From these circumstances canals may be separated into the two main divisions of lateral canals, and canals with a summit-level.

Lateral Canals.

2. *Lateral Canals.*—This first category comprises all derivations from rivers which are made either for the purposes of navigation, for irrigation, or for the supply of the water-courses of mills and factories. They may be made with a slight fall, so as to maintain a definite velocity in the water, or they may be made so that the respective portions between the locks assume the character of pools of stagnant water, without any perceptible flow. The former arrangement is applicable in cases where the navigation only takes place in the downward direction, or where the motive power of the water is to be made use of. An instance of a canal with a constant fall is to be found in the Canal de l'Ourc, near Paris. Upon it the navigation only takes place towards the capital, and the derivation itself serves also to carry the water to the town, for the public fountains, washing the streets, &c., and likewise to furnish the water requisite for the canal which runs round the north side of Paris.

Movement of Water.

The formulæ which express the conditions of the movement of waters in a canal whose section is constant and fall uniform, are usually given thus:

$$Q = S\,v;\ \text{from which equation, } v = \frac{Q}{S};$$

Q being the volume discharged per second; S, the section of the stream; v, the mean velocity per second. Or, M. de Prony gives another formula:

$$V = u l h\ .\ u = -0{\cdot}07 \pm \sqrt{0{\cdot}005 + 323\,\frac{i l h}{l + h}};$$

in which l is the mean width; h, the depth; i, the fall; u, the mean velocity per second. Of course it is to be observed that in all the formulæ used by the French Engineers, they have exclusively employed the metrical system.

3. In all canals where it is desired that the waters should have a definite flow, it is

indispensable that the fall be maintained uniformly throughout its length. On the Canal de l'Ourc, the Engineer, misled by his theoretical reasoning upon the shape assumed by the longitudinal profiles of rivers, adopted the plan of making the bed of the canal a species of catenarian curve. Upon this principle the fall in one part was made $0^{m}\cdot0000625$ per metre, in the other $0^{m}\cdot0001236$ per metre, instead of being a uniform fall throughout its whole length. The result was that the flow over the highly inclined portions became rapid and the depth feeble, whilst in the more level parts the flow could hardly be said to exist, and there was an excess of water.

An important observation made by Dubuat on canals of this description was to the effect that the aquatic plants retard the flow of the water to such an extent as almost to require that the inclination be double that indicated by theory.

4. It is usual to make all lateral canals, and even in many cases summit-level canals, with falls such as we are now considering, in order to compensate for the loss of water which takes place from evaporation, lockage, or infiltration. The direction of the movement of the navigation does not affect the rate of fall so much as the consideration of the stability of the works, although doubtlessly it is a very important element in the solution of the question. Practically, a fall which would produce a velocity of so much as 1 foot per second may be taken as the extreme limit for a canal navigable in both directions: 1 in 20,000 is, however, sufficient to produce a flow sufficient to compensate for the causes of loss above mentioned. The excess of water thus admitted into the respective ponds should be diverted round the locks by a culvert, rather than be allowed to flow over.

The works connected with lateral canals which differ the most from similar works upon summit-level canals, are those by which they communicate with the upper or lower parts of the river; those by which they occasionally pass from one bank to the other; and those by which they communicate with the sea, for nearly all the ship-canals may be classed amongst those now called lateral.

5. The communications with the natural bed of the river are of the most serious importance, for upon them depends the attainment of the facilities requisite for the management of the boats. The security of the latter from floods, the necessity of always commanding a sufficient depth of water, the importance of keeping the entry clear of the silt of the river,—all combine to complicate the difficulties and to increase the importance of this part of the work.

Upper Junction.

A careful examination of the most successful works of this kind leads to the conclusion, that the best principle to be followed in their execution is to place them at a rather acute angle with the natural flow of the river, the immediate junction being effected either by a large basin or by means of a curve. Under all circumstances, it is necessary to have a basin at the point of junction, on account of the differences of level the rivers are constantly exposed to from floods or tides.

If, at the point where the upper junction is established, there be not sufficient depth of water at the low summer-level, it is necessary to make a dam. If the river, however, be one which brings down much gravel or silt, depositions are likely to take place, which would render such works useless. The silting up of the bottom of the basin is only to be obviated by dredging, or by establishing powerful sluices to scour out the portions necessary for the navigation.

The feeders must be removed from the influence of floods; firstly, in order to avoid the dangerous effects of the cascades they might produce; and, secondly, to avoid the silting up of the canal by the muddy waters they bring down. The gates at the entrance are often made in separate portions when it is necessary to give them a great height, in order to attain the object of shutting out the floods. Sometimes the first basin of the lateral canal is so arranged that its level may be alternately above or below that of the river. In this case a double set of gates is necessary.

Outfall.

6. The outfall, or bottom junction with the river, may be either directly in the stream itself or in waters which communicate with it. The latter course is taken when there is danger of silting up, or of the formation of natural bars by the deposits of alluvium from the river. However the canal may communicate with the river or sea, it is necessary that the junction take place in such a manner as to facilitate the passage of boats from one to the other; that there be at all times a sufficient depth of water; that it be possible, should occasion arise, to establish sluices, as at the upper or feeder junction; and that the last basin be of sufficient dimensions to receive all the vessels which might require to lie there. This last basin also should, if possible, be without locks towards the upper part of the canal, and only be closed towards the river. On any lateral canal, where there is an important and active navigation, such basins or docks are of the highest utility, both for the safety of the boats and for the facility of commerce. On the lateral canal of the Mississippi, and that of Pont Chatrain, in a length of about five miles it was proposed to make no less than fourteen basins, besides three docks,—two at the entry and one at the outfall. At the outfall the same difficulty is met with, from the variations in the height of the river-water at the upper junction. But as the outfalls are usually in the tidal parts of the river, it is more necessary to render them constantly insubmersible than it is in the latter case. (See the plans of the upper junction of the lateral canal of the Rhône at Beaucaire, of the passage of the lateral canal of the Loire from one side of the river to the other, and of the junction with the Medway of the former Thames and Medway Canal.)

The communications between lateral canals and tidal waters are necessarily more complicated than those in ordinary rivers, from the great differences of level met with in the former. It is usual to take as the lowest point of such locks the levels of the mean neap-tides at low water. Such a course saves time in passing through the locks when once open; but boats are forced to wait at least six hours between tides, and the last basin is liable to be soon silted up.

Dimensions of Locks.

7. The question of the dimensions to be given to the locks is more simple in the case of lateral canals than in those of an ordinary character, for they are always certain to have an ample supply of water. They may then be made so large as to receive two or more boats at a time in the intermediate basin. It is questionable, however, whether the delay in the operation of filling the basin does not more than counterbalance the advantage of passing simultaneously several boats. At the outfall this consideration may be overruled by the facilities large locks offer for the entry of even sea-going vessels into the docks or basins.

Direction.

8. As far as it is possible, lateral canals are established in the valley in which the river itself runs, in order to avoid any extreme differences of level likely to require the execution of deep cuttings or tunnels, and also in order to have close at hand means of supplying any loss of water. Sometimes, to effect this, it is necessary to embank a portion of the bed of the river itself, as the hills often terminate abruptly in steep bluffs, washed at the foot by the stream. Such a case is met with in the lateral canal of the Tenessee, in the United States. When the floods of such rivers are of a moderate range, it is desirable to make the dams which separate the canal from them of a height sufficient to prevent their being overflowed; otherwise the works must be executed in such a manner as to resist the action of the water upon them, and facilities must be provided for the cleansing of the bed.

Meeting with Affluents.

9. Necessarily, in following the valleys of the main stream, lateral canals meet with all the affluents which fall into it; and these often give rise to serious difficulties. It is easy, of course, to pass small rills through culverts; but as these serve to carry off the natural drainage of the secondary valleys, they are in their turn exposed

to floods. Their free discharge in all conditions is therefore one of the first and most important means of insuring the stability of the canal. Sometimes also a variation in the physical and geological character of the country may render it advisable to change the position of the canal from one bank to the other, thus adding to difficulties met with in traversing an affluent. This is sometimes, as in the lateral canal of the Loire, effected by making the passage across the river at the natural level of the latter, and consequently exposed to all its irregularities; or by means of an aqueduct-bridge, which may produce very serious inconvenience by damming up the floods.

Canals with a Summit-Level.

10. Artificial navigable canals may be regarded as roads upon which the transport is effected in still water, so as to allow communication between two valleys having their own natural navigation, without forcing the boats to be unloaded. The objects to be attained in their execution are,—firstly, that their total length be the least possible; secondly, that the difference of level in the intermediate distances be as small, and the number of locks as few, as is consistent with a due regard to economy. The evaporation, the loss of water from filtrations, and the passage of boats through the locks, render necessary the execution of important works to insure an efficient supply of water. It often happens that this necessity leads into considerable expense, and causes a prolongation of the course of the canal.

It has been already observed, that the economical conditions of traction upon a canal are, that up to a speed of 3 feet 4 inches per second, the power, whether of men or of animals, is sixty times more effective upon a canal than upon a good road; and it is about five or six times as efficient as upon a level railway. The ratio of the power diminishes very rapidly as the speed of movement through the water increases, at least up to from 10 to 13 feet per second. We may then assert that, at least with the present form of canal-boats, canals are only adapted for the conveyance of heavy cumbrous articles which do not require a high speed. It is also to be borne in mind that the passage from one lock-level to another (an operation in all cases of from fifteen to twenty minutes' duration) adds materially to the length of time occupied in the transit.

The remarkable researches upon the movement of boats at high speeds in canals, begun by Messrs. Grahame and Fairbairn, and so skilfully continued by Mr. Scott Russell, have, as was before said, thrown a fresh light upon the subject of the resistance of water to the movement of boats. The laws which appear to regulate its action may be given in the words of the Report of the British Association for the Advancement of Science, as follows:

"The resistance of a fluid to the motion of a floating body will rapidly increase as the velocity of the body rises towards the velocity of the wave of displacement caused by the said motion, and it will be greatest when the two velocities approach equality.

"When the velocity of the body is rendered greater than that due to the wave, the motion of the body is greatly facilitated. It remains poised on the summit of the wave, in a position which may be one of stable equilibrium; and this effect is such that at a velocity of 9 miles per hour the resistance is less than at a velocity of 6 miles per hour behind the wave.

"The velocity of the wave is independent of the width of the fluid, and varies with the square root of its depth.

"It is established that in every navigable stream there is a velocity at which it will be more easy to ascend against the current than to descend with the current.

Thus, if the current flows at the rate of 1 mile per hour in a stream 4 feet deep, it will be easier to ascend with a velocity of 8 miles per hour on the wave than to descend with the same velocity behind the wave.

"The velocity of the wave of displacement is about 8 miles per hour."

It is unfortunate that the economical results of the application of the ingenious researches which led to the ascertaining the above interesting facts should not have succeeded.

11. At the present day the rage for railways has caused canal navigation to be somewhat neglected. A more efficient system of working them, a rectification of their course in some cases, and an improvement in the forms of the boats to be employed, would enable the public still to derive extensive benefit from a class of constructions far too much neglected at present. One vital error in the management of canals has been in the admission of private persons to the right of running boats upon them. In the hands of Companies able to pay for, and whose interest it would be to make experiments to ascertain the possible improvements to be introduced (either in the mode of traction or the form of boats), it is nearly certain that the present system would very soon be superseded. As it is, even the heavy traffic is leaving the canals, in spite of the disproportion of the exercise of power necessary to carry it upon railways.

The elements which enter into the constitution of the price of carriage upon canals shew, indeed, how in various ways the present organization of their traffic acts unfavourably upon their beneficial results. These elements are—

1st. The cost of loading and unloading, which can never be so economically done on a small as upon a large scale.

2ndly. The cost of transit, including the cost and wear and tear of boats and horses, and the expenses of the crews.

3rdly. The tolls, or the payment necessary to cover the interest upon the capital employed in the original construction of the canal, and the annual sums expended for its maintenance.

4thly. Any Government tax, insurance, risk, &c.

Now all these elements are susceptible of diminution, if the whole traffic were concentrated in hands of the Companies. The public would also gain by such a course, for it would enable canals to compete more favourably with railways, and thus to break down the monopoly the latter are arriving at.

Some canals with a summit-level are so situated that the fall is entirely in one direction, as, for instance, most of the canals in Belgium, and that from Arles to Bouc. The remainder have falls on both sides from the summit, and they thus traverse the mountain chains which divide the respective valleys between their points of arrival and departure. Such are the Canal of Languedoc, (the first executed in Europe,) and the greater number of canals executed in France, England, Germany, and the United States. The first kind may be considered as constituting canals with only one branch; the second are canals with a basin at the summit-level, and branches descending from it on both sides.

Choice of Direction.

12. When it is desired to construct a canal between any two particular points, it is advisable first to examine with great care the nature of the intermediate country, and to ascertain whether there be any points, even within a tolerably wide range, whose natural productions are of sufficient value to require a deviation in the course of the canal to insure their passage over it. The situation of all the mines, quarries, important factories, or large centres of consumption, must be noted, as upon them the advantageous results of the undertaking will mainly depend. Trial levels and cross-sections of the country through the different routes which appear suitable, must

be taken, to ascertain the nature and quantity of work to be executed, whether of cutting, tunnel, or embankment. The various springs and water-courses must be noted, and the actual uses to which they are applied carefully considered. In densely peopled and highly civilized countries, like our own, we often find indeed that more difficulty and expense arise from interference with the waters of ornamental gardens, than from streams more usefully employed. In new countries and the colonies, the use of water privileges complicates the questions connected with the diversion of or interference with streams. The main object being, however, to put the two extreme points in communication, it is essential that the route chosen be as short as possible, without losing sight of any collateral traffic, or incurring needless expense.

Summit-Level.

13. In case the country to be traversed be of a very irregular nature, one of the most important questions to be resolved is the position of the summit-level. This must be placed as low as possible, for the double reason of obviating the necessity for many locks, and in order to insure the most perfect supply of water.

Occasionally, but very rarely, the point most fitted for the summit-level is found to be the position occupied by a lake or pond of sufficient importance to supply the lower portions of the canal. The pond of Longpendu is an instance of this remarkable geological formation. It pours its waters into the Loire on one side, by a little river called the Bourbince, and into the Saone, on the other, by the Heune. The pond of Cony is also in an analogous position, for it communicates on the one side with the Moselle, by the Niche, and on the other with the Saone. Such natural indications of the route are, however, quite exceptional, and it much more often happens that the central ridge of the chain to be passed is obliged to be traversed in tunnel.

More than ordinary care must be taken to ascertain exactly the sources of supply of the summit-level, and to proportion it exactly to the wants of the navigation. All the streams which can be brought into it must be carefully gauged in every state of the temperature or of the year, and the geological constitution of the neighbouring country examined, to ascertain whether it be possible to secure a supply of water by wells. The quantity of water to be furnished by the summit-level must depend upon the length of canal to be fed by it,—the length, breadth, and height of the locks,—and the number of boats to be passed in both directions. In case the probable supply of water be exposed to occasional interruptions, or be deficient in quantity, it may be advisable to substitute inclined planes for locks, or it may be necessary to follow the system employed on some of the American canals, of substituting a railway for a considerable distance.

In the branches from the summit-level it is desirable that as long reaches of level canal as possible should be constructed, to admit of the concentration of locks. On some canals, where two or more locks have been constructed close to one another, the Companies have placed a man specially charged to keep them in order; and where they have been detached, the damage done to the locks has often forced them to erect a lock-house for the service of a single one.

Dimensions of Canals.

14. The dimensions to be given to a canal require also very mature consideration, especially when the total development of the inland navigation is considerable. In all countries but England, the tendency of the river navigation is to employ a larger and deeper kind of boat than was employed before the works for the improvement of rivers were effected. Our own large tidal rivers, however, as was said before, place us in an entirely exceptional position. Sea-going vessels come so far inland that it is not necessary to send our canal-boats to sea. Our mode of working canals also renders it preferable to use a boat able to be drawn at a small expense and

worked with few hands. Mr. Chapman observes that "the system of small canals is peculiarly eligible for countries where limestone, coal, iron ore, lead, and other ponderous articles not liable to damage from being wet, or likely to be stolen, are the chief objects to be attended to; and where the declivity of the canal runs transversely to the course of the canal, which will generally be the case along the sides of mountains, at an elevation above the irregular ground at their feet." But we must not forget that both theoretically and practically the conditions of movement through a small canal are less advantageous than when it takes place through a wide one. The section of the boat in the former bears a greater proportion to the water section than in the latter, even when small boats are used. The resistance of the water is consequently greater.

On the Rhône, the barges in use carry 75 tons; on the lower Seine, between Paris and Havre, they are, as already mentioned, sometimes as much as from 500 to 600 tons burthen; on the Meuse, barges are employed of 250 tons burthen, drawing 4 feet of water. The steamers which navigate those parts of the Tenessee formed by canals are of 120 tons burthen, with a draught of water of 5 feet. The limits of the size of the boats are not finally determined; and the inference to be to be drawn from the above facts is, that in the future development of commerce it is desirable to make a canal as wide as possible, in accordance with motives of economy and the supply of water.

On some of the French canals the width was settled without any reference to the dimension of the boats frequenting the rivers thus put into communication. The consequence was that goods were necessarily transhipped at both ends of the canal at an enormous expense. The Administration of Public Works in that country, to avoid a recurrence of this blunder, have adopted, since the year 1822, the following dimensions:

Canals for 'grande navigation' are made 33 feet 4 inches wide upon the floor-line, and 49 feet 6 inches upon the water-line, by 5 feet 5 inches depth of water. The locks are 106 feet 8 inches long by about 17 feet wide; the towing-paths 13 feet wide.

Canals for 'petite navigation' are made only 33 feet 4 inches wide upon the water-line, and 22 feet on the floor, with a depth of water of 5 feet. The locks are 100 feet long by 9 feet 1 inch wide. The Canal de Berri is of this class.

Some of the French canals for steam navigation have locks from 26 to 40 feet wide, and of lengths between 150 and 233 feet in clear of the gates.

In England, no very definite rule appears to have been followed in fixing the dimensions of canals. Those executed for the important internal lines vary from 31 to 48 feet upon the water-line, with an average depth of above 5 feet. The locks are generally 70 feet in length by from 14 feet 6 inches to 18 feet wide. Small canals, in the mining districts, have in some cases been executed with a width of not more than 16 feet upon the water-line, and they range from that to 28 feet. The locks are made of the same length as for large canals, but of only half the width.

Ship canals have been made of much larger dimensions, such, for instance, as the Caledonian Canal, which has in parts 122 feet upon the water-line, with a depth of 20 feet. The Gloucester and Berkeley Canal has a water-line of 70 feet, and a depth of 18 feet. The Thames and Medway had a width of 50 feet by a depth of 7 feet; the Ulverstone, 65 feet by 15 feet; the locks, of course, being in proportion to the size of the canals.

In the United States, the same irregularity occurs in the dimensions of canals as in our own country. Two extreme cases of ordinary works may be cited, in the Erie and the Morris canals. The first is 70 feet wide on the water-line by 7 feet

deep; the second is 32 feet wide by 4 feet. The lateral canal of the St. Lawrence is in some parts as much as 150 feet wide, and occasionally as much as 10 feet deep. All such ship canals are, however, executed in situations where an unlimited supply of water is to be found.

Supply of Water. 15. The dimensions of the canal being once settled, it becomes necessary to determine the positions and dimensions of the reservoirs and feeders. The consumption of water arises from several causes; some of which are regulated by the activity of the traffic,—some of them are independent of it.

The causes of loss, independent of the navigation, are—firstly, the evaporation; secondly, the filtration; thirdly, the escape through the defective parts of locks or other works; and fourthly, the loss occasioned by filling the whole canal after the waters have been let out for the purpose of repairs.

The causes of consumption of water, dependent upon the navigation, are—the loss occasioned by lockage, and the quantities of water it is often necessary to bring down from the upper levels to compensate for the deficiencies caused by the too sudden affluence of boats to the lower ones.

Evaporation. 16. The loss of water by evaporation is greater in proportion to the surface exposed and the nature of the canal. It varies with every position, and, in the same country, with the seasons, according to the different hygrometric states of the air, the prevailing winds, and the extremes of heat or cold. The quantity of rain which falls upon, or may run into, the canal, must be deducted,—but these are very variable. In warm latitudes showers are rare, and although they are sometimes excessive, they are of little importance as far as they affect the supply of a canal, which requires, above all things, an uniformity of level upon its water-line. In the temperate latitudes of Europe, the mean fall of rain may be taken at 2 feet per annum, and the evaporation at from 4 to 5 feet, in districts through which canals usually pass. The daily loss under such circumstances is, then, about from $\frac{1}{16}$th to $\frac{1}{12}$th of an inch per day, on the average. In the summer, however, the evaporation is great without any compensation, and in such periods it may be necessary even to calculate upon a loss of not less than 4 inches in the twenty-four hours. Allowances for the waste of water from this cause must be calculated, and also that upon the locks, reservoirs, and feeders of canals.

The loss from filtration must depend upon the nature of the strata traversed and of the materials used to form the bed of the canal. When these are homogeneous, the rate of filtration depends upon the surface wetted, the depth of the water, the extent of the permeable strata at the bottom, and upon their degree of saturation. The amount of loss from this cause usually varies from one-half to as much as twice that from evaporation. Instances have been known in which all the water of a canal has disappeared in twenty-four hours; in other cases the depth of water lost has been no less than 2 feet 8 inches in that time, even after the canal had been in use for fifteen years; in others the navigation has been suspended for the greatest part of the year. When such serious losses do occur, the best remedy appears to be to line the bottom of the canal with a bed of concrete executed in hydraulic lime. Puddling is but an inferior substitute, for the clay of which it is mainly composed is liable to shrink and crack with great heats, and thus takes on itself the action it was introduced to remedy. On the Canal St. Quentin, where the filtration took place to such an extent as to render navigation impossible during eight months of the year, concrete was introduced in the manner shewn in the following sketches; a small step being formed in the angle to prevent the clay lining from slipping. In ordinary cases an allowance for filtration of 2 inches per 24 hours may be considered as ample; but it must be observed, that the first time water is turned on, even upon a water-

tight bed, the level will fall at least 4 inches in the 24 hours; and this loss will be repeated every time the canal is laid dry for repairs.

Fig. 1.

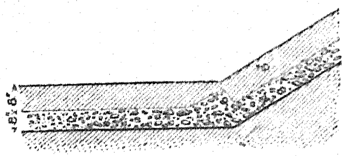
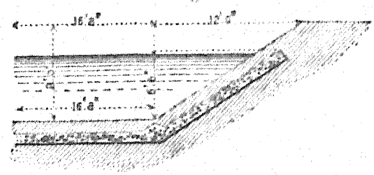


Fig. 2.



Canal of St. Quentin.

Loss from Locks.

17. The defective execution of lock-gates gives rise to a very serious loss of water. Even when they are new, the weight of water in the upper basin forces the water through the meetings of the heel and mitre posts. After some years' wear this necessarily augments, and attains sometimes such importance as to give rise to a loss of not less than 10,000 feet cube per 24 hours from one lock. In order to be sure of a constant supply of water, it is advisable to establish the reservoirs, with a view to prevent such a loss.

Loss from cleaning the Bed of a Canal.

18. The loss of water occasioned by the repairing and cleansing the beds of canals depends greatly upon the length of time during which they are left dry. Every reason, economical or sanitary, requires that this should be as short as possible; for not only is the navigation suspended during these operations, but also there are dangerous exhalations from the slimy bed, and at the same time the latter is exposed to crack, to shrink, and dry, in proportion to the time it is laid bare. Under the most favourable circumstances, as explained in the last paragraph, there must be a great loss from the new filtrations. A saving of water may sometimes be effected by cleansing one bay or basin at a time, working upwards; so that the immediate loss may nearly be confined to the contents of the longest basin, with the filtrations in addition.

Loss by Lockage.

19. The loss occasioned by the passage of boats through the locks must depend not only upon their number, but upon their proximity to one another, and also upon the relative directions in which the navigation takes place. A tolerably accurate estimate may be formed upon the supposition that every passage through a lock of the ordinary dimensions of large canals will require nearly 18,000 cubic feet of water. This quantity is far more than is absolutely necessary to restore the level in case of passage, but there is always a waste from the defects of the gates or from carelessness of the lock-men, which renders it advisable to count upon double the quantity absolutely required.

When numerous boats remain in a canal, they give rise to a displacement of water which can only be compensated for by a supply from the upper levels. The quantity necessary to establish this compensation has been taken at $\frac{1}{12}$th of that required for the passage of the locks.

Reservoirs.

20. The dimensions of the reservoirs must be calculated so as to meet all the future possible requirements of the navigation. The upper basin, or summit-level, should itself be established in such a position as to act to a certain extent as a reservoir, and consequently occupy the lowest position in the mountain range. But there is often an inconvenience in deriving all the supply from one source, namely, that the water is likely to attain a velocity susceptible of injuring the works, or at any rate of retarding the navigation. Artificial reservoirs, wherever placed, present great advantages over the irregular supplies from springs or streams, as it is easy to regulate the flow from them in such a manner as to maintain a constant level

in the canal; whereas streams furnish occasionally ten times as much as at others, and are often exposed to periods of perfect drought.

Direction of Canal.

21. The preceding calculations of the loss of water, &c. suppose that the Engineer has already traced out, provisionally, the direction to be followed by the canal, so as to form an approximate estimate of the length and the number of locks to be constructed. Having also ascertained the probable supply of water, the definitive line must be chosen. In leaving the summit-level, the two descending branches follow the valleys of the water-courses which determined the position of that point. If it be possible, that side of the valley should be chosen which presents the fewest affluents and is the least intersected by common roads; bearing always in mind that circumstances may arise in which it is desirable to use the secondary streams as feeders for the canal.

Rocky soils are the most favourable for the foundations of locks, bridges, or such works; but they render the earthworks very expensive. If they be of a porous or fissured nature, they are likely to cause dangerous filtrations. Schistose rocks decompose under the combined actions of air, water, and frost; and then they pass into a soft mud. If the soil be clayey, it will be sufficiently solid for the foundations of the locks, and it will be well adapted to retain water, and easily excavated; but if the beds be inclined, or if springs filter through at any intermediate height, such clay soils are exposed to dangerous land-slips, certainly the most serious difficulty to be met with in the execution of engineering works.

Whenever it becomes necessary to pass from one side of a valley to another, the position must be chosen so that the passage be as short as possible, and that the land upon the banks of the canal present sufficient solidity. The curves by which the junctions between the changes of direction of the course of a canal are effected must be made as easy and of as large a radius as is convenient. They must at least be such as to allow two boats to pass one another easily.

In all civilized countries many difficulties arise from the complicated relations of property, which render it impossible to carry out the works in the most desirable directions. Too much care and pains cannot, therefore, be bestowed upon the preliminary investigations of the country to be traversed. Maps must be made, indicating the boundaries of every parish and township, what counties the canal is intended to traverse, the proper names of the owners and occupiers of the land. All the public and private roads, paths, or communications which exist in the direction to be followed; all brooks or streams, and particularly such as lead to or supply a mill; the situation of any houses, villages, or towns, upon the line, and even within some miles of the intended canal, require to be carefully ascertained with the greatest accuracy.

Position of Locks and Bridges.

22. A complete plan of the line being made, indicating all the lateral cuts, branches, feeders, and reservoirs, the precise position of the locks, bridges, and culverts must be definitively arranged. Those of the locks will, to a certain extent, be regulated solely by the nature of the ground, and should be chosen at the bends in plan, or at the points where the natural level of the country changes rapidly; and it is desirable that the positions of locks coincide with those of the bridges. In such cases there is a considerable saving of masonry effected by making the wing-walls of the locks serve as foundations for the abutments of the bridges. At the intermediate positions, bridges must be erected so as to cause as little derangement of the existing traffic as possible. The dimensions of culverts must be sufficient for the discharge of any floods likely to occur in the secondary valleys: at times they may be obviated by means of new channels opened to concentrate the flow of several small streams into one, situated in a more favourable position for the establishment of a new outfall.

The proportion of locks per mile of canal is necessarily very variable. A Table is subjoined of that which is to be found upon some of the most important canals in our own country, in France, and in America. It is, however, only given as an approximation, and as a means of comparing the probable results to be obtained from any new work of the kind. There is one lock in a distance varying upon the several canals as follows:

ENGLAND.

On the Grand Junction, one lock in	. .	0·65 miles English.
Grand Trunk ,,	. .	1·25 ,,
Thames and Severn ,,	. .	0·67 ,,
Leeds and Liverpool ,,	. .	1·43 ,,
Kennet and Avon ,,	. .	0·88 ,,
Rochdale ,,	. .	0·33 ,,
Birmingham ,,	. .	1·10 ,,
Forth and Clyde ,,	. .	1·03 ,,
Mersey and Irwell ,,	. .	0·60 ,,
Birmingham & Liverpool ,,	. .	1·08 ,,

FRANCE.

On the Canal du Rhin, one lock in	. .	0·87 miles English.
,, du Midi ,,	. .	1·89 ,,
,, de Bourgogne ,,	. .	0·80 ,,
,, du Centre ,,	. .	0·87 ,,
,, de St. Quentin ,,	. .	2·12 ,,
,, de Berri ,,	. .	1·28 ,,
,, du Nivernais ,,	. .	0·66 ,,
,, du Haut Rhin ,,	. .	0·93 ,,
,, de l'Ille et Rance ,,	. .	1·64 ,,

On the canal from the Rhône to the Rhine a lock occurs in every distance of 1·31 of an English mile.

In America, upon the Erie Canal, one lock occurs in every distance of 4·36 miles; on the Chesapeake Canal, one in a distance of 4·61 miles.

Telford on Springs.

23. Telford laid great stress upon the necessity which existed for a series of investigations into the nature of the substrata and the heights to which land-springs might rise. He cautions Engineers, very properly, against a very dangerous error that the latter may become available for the supply of the canal. It often happens, as he justly observes, that such springs, from having a variety of other vents or outlets, at or very near to the same level, are incapable of being dammed or raised higher than they were before. When the canal is filled with water to a higher level, the course of such springs can be reversed, and the porous strata, through which they passed, may serve to absorb and discharge the water at other places to a very fatal extent. Land-springs, or such as run only in winter, have generally the same effect, and in summer as copiously take in water, when their own source fails, as they before discharged it.

After all these preliminary investigations have been made, it will be necessary to revise the whole plans, in order to secure an equalization between the cuttings and embankments; to ascertain that the locks, bridges, and other works are placed in the most advantageous positions; and that the curves as well as the general direction of the canal are of the most favourable nature. The preliminary estimate will have to be based upon the results of this last and definitive plan.

Execution of Works upon Canals.

24. *Earthworks.*—When the works are really to be commenced, the resident Engineer must proceed to trace accurately the levels of the different ponds, or reaches, of the canal, and to put in level-pegs, more or less, according as the ground is more or less undulating, as he proceeds. In canal, as in railroad earthworks, the great object to be attained is, that the stuff dug from one part of the work shall, with the least labour or distance of moving, exactly supply or form the banks that are to be raised in another; so that upon the completion of the works no spoil-banks, or heaps of useless soil, shall remain, or any ground be unnecessarily rendered unfit for cultivation by the excavations or pits of the side cuttings. Six different cases will be found to occur in the cutting or forming of a canal, as in the accompanying sketches; the main principles, to be observed in all, being to economize the removal and transport, to a distance, of material; and in cases where deep cutting occurs, to make a berm which shall prevent the disintegrated portions of the rocks on the upper side from falling into the canal: any streams likely to fall into it from the upper lands must also be intercepted if they be likely to bring down any alluvial matters.

Fig. 3.

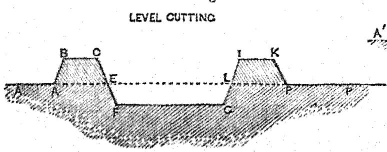


Fig. 4.

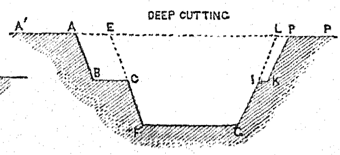


Fig. 5.

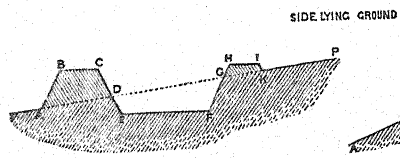


Fig. 6.

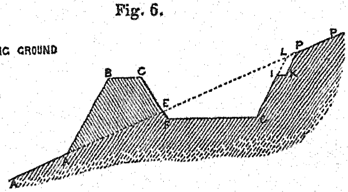


Fig. 7.

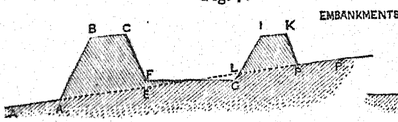
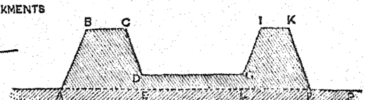


Fig. 8.



The Engineer will find abundant instances of diagrams 4, 7, and 8, in all their degrees, and in which there will be either a want of stuff to form the banks, as in 7, or a redundancy from the deeper cutting, as in 4; and the perfection of his skill will be shewn in so conducting the line that every embankment (as at 7) shall have deep cutting at both, or, at least, one of its ends, to furnish the extra stuff with the least expense in moving it. In like manner, every deep cutting (as at 4) should have embankments at one or both of its ends, to receive the extra stuff. In practice, an infinite variety of such cases will occur, rendering necessary great skill on the part of the Engineer in laying out the line so as to balance the amounts of his earthwork, and to avoid inconvenient sharp curves, such as Telford so strongly censures in many English canals.

The first operation in staking-out the ground will consist in tracing the outside line

to be followed by the cutting or embankment when completed; and subsequently in staking-out the centre line. The positions of the different works to be erected must then be indicated, and provision made to secure, in one case, the earth necessary to back up the bridges or locks, and, in the other, to widen out the banks when it becomes necessary to erect a toll-house, warehouse, or other building.

In narrow canals, or branches of that description, wider places must be provided at intervals, to allow the barges to turn and to lie in whilst others pass them. These must be so situated that bargemen can mutually see each other approaching, and be able to pass one another without being obliged to drag their boats back again to a passing-place. At the same time, they should be chosen in such low positions as will admit of widening the canal without much extra expense.

When the line is staked-out, the foundations of the locks and bridges should be immediately put in; the several drains and culverts executed as rapidly as is consistent; any water-pipes for the supply of neighbouring properties laid down at such depths as to preclude any possibility of their injuriously acting upon the canal. The vegetable soil should also be carefully removed from the whole surface of the ground.

Puddle.

25. Telford, and perhaps the bulk of our Engineers at the present day, attached very great importance to the study of the means of rendering canals impermeable by means of puddle; and they consequently devoted much attention to ascertaining whether materials fit for the purpose were to be obtained easily. The introduction of the use of concrete made of hydraulic lime has simplified the question in many cases; for its expense, although considerably greater in the first instance, is more than compensated for by the economy it introduces by effectually stopping filtrations. The eventual saving, in countries at least where lime is at a reasonable price (every lime being susceptible of becoming hydraulic to any required degree of energy), is, however, decisive upon the question. Yet, in countries like Holland, and in some of our own Colonies, the use of puddle may still be necessary. Puddle consists of clay reduced to a semi-fluid state by working and chopping it about with a spade, while water just in the proper quantity is added, to render the mass homogeneous, and so much condensed that water cannot afterwards pass through it, or only very slowly. The best puddling stuff is rather a lightish loam, with a mixture of coarse sand or fine gravel in it: very strong clay is unfit for the purpose, on account of the great quantity of water it will hold, and its disposition to shrink and crack as this escapes. Vegetable mould or top-soil is very improper, on account of the roots and other matters liable to decay and leave cavities in it, but more on account of the temptation that these afford to worms and moles to work into it in search of their food. Where puddling stuff is not to be met with containing a due mixture of sharp sand or rough small gravel stones, it is not unusual to procure such to mix with the loam, to prevent moles and rats from working in it; but no stones larger than about the size of musket-balls ought to be admitted. Telford states that the operation of chopping up and beating the puddle consolidates it to such an extent, that it only occupies two-thirds of its original bulk; and that the commonly received opinion in his day, that the first coat should be allowed to dry before the second and succeeding ones were applied, was not founded upon any rational grounds. Whatever be the expense of rendering canals impermeable, it is nevertheless so evidently the interest of all parties connected with them, either as shareholders or neighbours, that they be rendered so, that it is to be desired some stringent legislative enactments were enforced to insure their fulfilling the above condition.

Observations to be made upon execution of works.

26. In England and in the United States the execution of large public works is generally carried out by contractors, who undertake the whole or portions of the work. In France and Germany, however, and doubtlessly in our own East Indian

and other Colonies, that useful class can hardly be said to exist; at any rate, it is very difficult to find contractors possessing the capital and skill required to carry on works according to English practice. Under these circumstances, the Engineer is forced to treat, as it were, directly with the sub-contractors or piece-workmen, or even to have some works executed by day-labourers. His duties in this case become complicated by the financial parts of the execution, and require great knowledge, both of the manners and mode of treating workmen, and also of the amount of work they ought to do. Under any circumstances, and even when a contractor is employed, it is desirable that careful observations should be made upon the number of men employed, and upon the mode of carrying on the works. Too strict a superintendence of the different operations is impossible; and the system of leaving the contractor almost master, so to speak, which is the unfortunate tendency of our actual method, should be carefully guarded against. In letting earthworks, all barrows, wheeling-planks, horsing-blocks, and other implements, are generally found by the Company. Formerly, in England, a stage of wheeling was considered to be from 20 to 25 yards in length, and the price per cubic yard was fixed in proportion to the number of stages the soil was to be moved. The French Engineers reckon the stage at 33 yards upon the level, and at 22 yards when upon an incline of 1 in 10. Where the distance to be traversed exceeds 100 yards, horses may be economically employed. Upon railways, it may be added, the use of a locomotive is preferable if the lead be above 1¼ mile.

Consolidation of Embankments.

27. When the canal is to be carried upon an embankment, it is necessary that the earth be well consolidated before it is attempted to turn in the waters. The French Engineers insist that all such works be executed in layers of not more than 6 inches in thickness, and that each course be well rammed, after being previously watered with lime-water.

Bottom, or Bed, of Canal.

28. If the bottom of the canal be puddled, it must be executed in several courses, under the most careful and incessant superintendence. The courses should never exceed from 10 to 12 inches in thickness; and when the whole is completed, the puddling must be brought to a total thickness of 3 feet. When the top course is set, a layer 18 inches or 2 feet thick of the common soil or stuff should be laid evenly upon it, and the bottom levelled: this covering of the bottom should be rather dry, and not in large lumps, or with great stones or sticks in it. The sides are not usually puddled to so great a thickness as the bottom: 18 inches is the ordinary thickness, which is again covered over with the common soil to prevent the slipping of the puddle; and it may be here repeated, that when the extra depth of excavation required for the puddling, and the amount of labour involved in its execution, besides the very doubtful nature of the results attained, are taken into account, the advantages of employing it, instead of a good hydraulic concrete, are more than questionable. The solution of this question is, however, one which must entirely depend upon local considerations, and therefore admits of no absolute decision *à priori.*

Whatever be the means adopted to insure the impermeability of the bed of the canal, the attainment of that state must be a *sine quâ non* for its economical working. All authors upon the subject, all the experience of the most scientific Engineers, are in accord in this respect. Telford repeats, again and again, his cautions upon the necessity of its being executed in the most perfect manner, and also upon that of preventing any springs from rising up through the bottom.

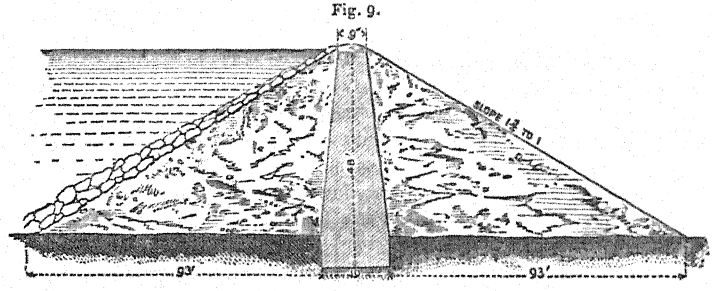
The management of spoil-banks (or the deposits of earth extracted from the cuttings in excess of the embankments), and of the side-cuttings (or excavations to furnish earth when the cuttings are not sufficient in quantity, or would require too heavy an expense of transport), is precisely the same with canals as it is with common

roads or railroads. The mounds produced by the former should not be formed until the vegetable soil has been removed from the position they are to occupy; when dressed off, the same soil should be spread over the top, to encourage the growth of vegetation.

Works of Art upon Canals.

29. *Reservoirs.*—Reservoirs ought to be entirely distinct from the navigable parts of the canal, in whatever position they may be placed with reference to the summit-level. It frequently happens that it is necessary to lay dry the whole length of the canal, and under such circumstances there would be an evident advantage in isolating the reservoirs. If any natural ponds are to be met with, they should be made use of; but considerations of economy in the original construction must not lead to the neglect

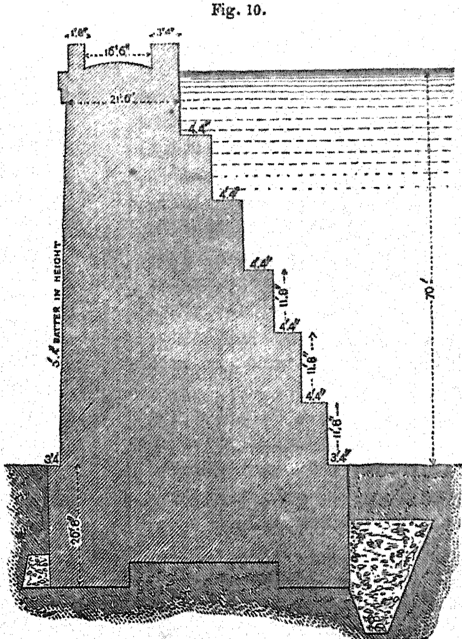
Fig. 9.



Marsden Reservoir, Huddersfield Canal.

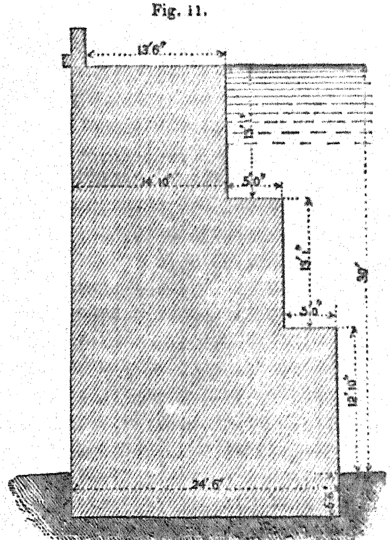
of furnishing artificial means of supply, in case the position of such ponds be not adapted to the wants of the canal.

Fig. 10.



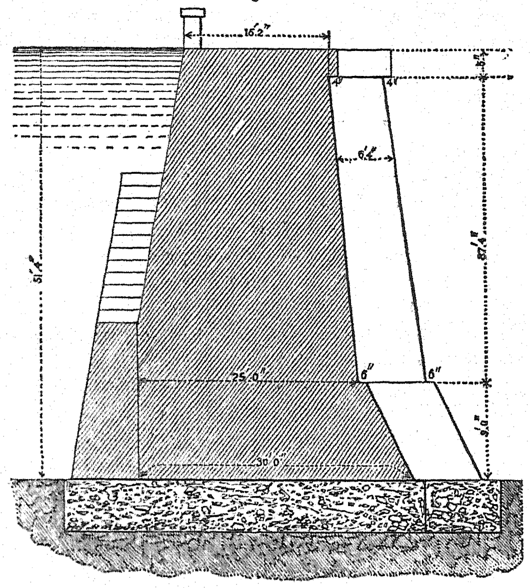
Canal de Bourgogne—Reservoir de Gros Bois.

Fig. 11.



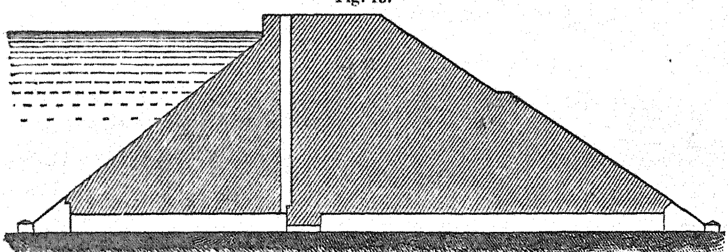
Reservoir of Glomel—Nantes to Brest.

Fig. 12.



Reservoir of Lampy—Canal du Midi.

Fig. 13.



Reservoir of Torcy.

Position of Reservoirs.

30. When reservoirs are not formed by means of natural ponds, they are placed in valleys, the heads of which are dammed across so as to retain all the waters which may fall upon the upper country. It may happen that a considerable supply of water is to be derived from a parallel secondary valley, by carrying the stream through the separating ridge in a tunnel. In the main valley, the position of the dam must be chosen at the point where the valley is the narrowest, or where the strata on which it is to be constructed are such as to be able to resist the tendency to crush, or to slip, caused by such enormous insistent weights.

The conditions necessary to be observed in the construction of reservoirs, as far as regards the quantity of supply, have been already discussed. The water they furnish must be at all times available for refilling the canal, and must also be so free from alluvial matters, so devoid of velocity, as not to be likely to injure the banks or to choke up the canal. There must be provided, then, in every reservoir: 1st, A dam to close the head of the valley, in which, means to let off the water, and to regulate its flow, must be provided. A parapet varying in height according to the surface

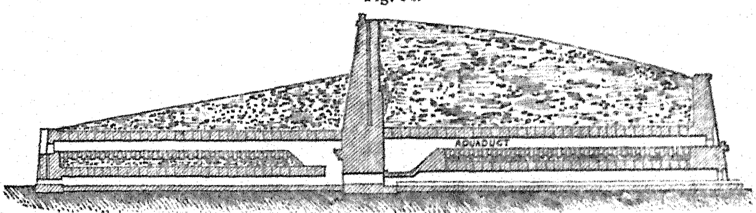
of the basin and the prevailing winds must also be provided. 2ndly, A waste weir, or overflow, to carry off any surplus water which may enter the reservoirs. 3rdly, An aqueduct at the bottom, through which any muddy water may escape, or by means of which the reservoir may be emptied in case any repairs are required. 4thly, A temporary basin in which the mountain streams may deposit the mud and gravel they bring down.

Dams.

31. Dams of reservoirs may be executed in various manners, either of earthwork, lined with puddle, and consolidated on one or both sides by a paving of dry stone pitching; or by an embankment faced on both sides by walls; or finally by a wall. They are sometimes executed of a curvilinear form in plan, presenting their convex side towards the interior. Reservoirs have been executed in England and France with dams of not less than from 40 to 70 feet in height, which have stood very well. Some of the dams executed by the Moors in Spain are of more extraordinary dimensions still: the dam of the Fountain Reservoir of the Croton Aqueduct at New York, which covers a surface of 400 acres, is not less than 38 feet in height, and on the Rideau Canal there is one 60 feet high.*

When the dams of reservoirs are executed with an embankment between two or more walls, there is great danger to be apprehended from the swelling of the earth upon its imbibing water. The thickness of the walls has to be so much augmented to resist this action, that there does not appear to be any real economy in the mixed system. Under usual circumstances, it appears preferable to form the dam entirely in masonry, especially when good hydraulic lime is easily obtained. The dam should be made of middling-sized materials, and a coat of hydraulic concrete interposed between it and the water.

Fig. 14.



Reservoir of Couson, Canal de Gisors.

Whatever be the mode of constructing the embankments and dams of the reservoir chosen, it is an indispensable condition that the soil upon which it is to be built be of a nature not to allow of unequal settlements, and that it do not permit the passage of water. To secure these conditions it has often been necessary to carry down the foundations to such a depth as to require as much masonry below as above the natural level of the ground; in some cases as far as 50 feet.

Telford recommends, that if the strata upon which the reservoir is to be formed be of a porous nature, such as to allow of the infiltration of the water, the whole of the bottom of the valley be puddle-lined. The face of the dam must also in such a case be puddled towards the water, and it is even advisable to make an extra puddle-ditch in the centre, to guard against any accidental slip of the face lining. There are few operations in canal-making of more importance than those necessary to economize water in reservoirs, and the enormous expense entailed by the above-named precautions, to insure their impermeability, will shew the necessity for extreme caution in the choice of their positions, as well as a knowledge of Geology.

In executing the dams, trenches should be dug in the foundations, so as to break

* See vols. i. ii. and iv. of Professional Papers of the Corps of the Royal Engineers.

their horizontal line into a series of steps. Such a course offers a greater resistance to the lateral thrust of the water, and renders the dam less liable to slip. Of course the same precaution must be taken for the sides. Another advantage in these steps is, that they break the direction of any stream which may filter through the bank, and facilitate the deposition of any earthy matter carried by the water, causing the crack 'to take up,' to use the workman's phrase.

If the dam be executed in earthwork, it should be made from 13 to 16 feet wide at top, with slopes varying from $1\frac{1}{2}$ to $2\frac{1}{2}$ base to 1 in height. The best mode of making such dams appears to be to employ clay mixed with a certain proportion of sand; this should be watered at every course with a little lime-water, and well rammed, taking care to leave sufficient asperities, or toothings, upon the face of the different layers, to prevent the upper ones from sliding upon those beneath them. It is also necessary to follow on the work rapidly, to prevent the lower courses from drying before the upper ones are added.

Reservoirs, if enclosed by a dam of masonry, require precisely analogous precautions; the filtrations must be prevented as far as possible by stepping the foundations; care must be taken to break the horizontality of the beds. If the length of the dam be considerable, it will be necessary to introduce many counterforts; not so much for the purpose of saving masonry in the dam itself, as to resist the tendency of long bodies of walling to assume a catenary form under constant and heavy pressure.

The size of the reservoirs of the more important canals is such that they become, in fact, lakes of still water; and as their positions are often of a nature to expose them to the violent action of the prevailing winds of the mountain gorges, it is necessary to carry the dam about 5 feet above the water-level, to prevent the waves from washing the upper portions of the enclosure. Precautions must be taken, in the event of the waters overflowing the crown of the dam, to prevent injury to the structure. An accident of this nature took place during the execution of the works for the Croton Aqueduct, when the floods, rising over the dam in an extraordinary manner, carried away in a few hours the whole structure, and spread death, ruin, and desolation throughout the course of the stream.

Thickness of Walls.

32. From the movements remarked in the masonry of some dams, it would appear to be necessary to give the walls double the thickness required by the strict application of theoretical rules. Indeed, in such works the tendency to slip upon the bed complicates the conditions of equilibrium to a serious extent; it is, in fact, greater than the tendency to turn over on the extreme edge. Representing the height of the water by h, the thicknesses which appear to be the most advisable to give to the dams of masonry at the following points in their height, are x, being the thickness sought:

At the top, $x = h \times 0{\cdot}30$
In the middle, $x = h \times 0{\cdot}50$
At the bottom, $x = h \times 0{\cdot}70$

Such thicknesses are, perhaps, rather in excess; but the terrible consequences arising from the bursting of a dam, and the more perfect impermeability of a large mass of masonry, should rather induce a preference in this direction.

The importance of reservoirs to the regular working of canals may be judged of by the colossal constructions executed, in dry warm climates especially, to insure their constant supply.

The Birmingham Canal has a reservoir of 80 acres surface, with a depth of 45 feet at the head of the retaining bank. That of the Union Canal of Pennsylvania is not less than 730 acres superficial, by an extreme depth of 40 feet, and it holds 572,509,000 cubic feet of water.

The principal reservoirs in France are specified in the following Table, with their height of water, capacity, &c.

Canal.	Reservoir.	Nature of dam.	Height of water.	Capacity.
Du Midi	St. Fériol	Earth and wall	105 ft. 0 in.	223,090,000 cubic ft.
De Bourgogne	Gros Bois	Wall	69 „ 6 „	300,510,000 „
„ „	Cercey	Earth	39 „ 3 „	130,900,000 „
Nantes à Brest	Vioreau	Wall	33 „ 0 „	262,395,000 „
Du Centre	Torcy	Earth, lined	36 „ 3 „	83,300,000 „
De Briare	Grande Rue	Earth	26 „ 6 „	189,000,000 „

Distribution from Reservoirs.

33. For the service of the canal, the water is usually drawn from the reservoirs by means of a series of sluice-gates, placed at different levels to draw off the water in such a manner as to prevent its acquiring any velocity from the head above it. In some reservoirs the sluices are replaced by large cocks, so constructed as to be worked by screws; but whatever means may be adopted for distributing the water, it is necessary that the flow be kept under the most accurate and instantaneous control.

Occasional Resources.

34. It very frequently occurs that springs, streams, or rivers, in the course of a canal, may be advantageously substituted as a source of supply for the more expensive means furnished by reservoirs. This method is more commonly employed in the United States, where the greater portion of the canals are replenished by feeders from such accidental sources. In Belgium and Flanders it frequently happens that a set of locks occurs in such immediate proximity to one another, that there is advantage in returning the water, passed through the locks, to the upper level, by means of steam or water power. Local considerations must, however, decide the question as to what system should be adopted in every particular case.

35. When, therefore, feeders from side-streams are to be made use of, their beds should firstly be rendered as impermeable as possible; the new course of the feeder should be made as direct, and the fall be as small, as may be required to conduct the water with an uniform velocity suitable for the purposes of the canal. As with the streams directed into reservoirs, care must be taken to prevent them from carrying any impurities likely to obstruct the bed of the canal. The use of streams for mill-power renders their application for the supply of canals often extremely difficult. In certain positions springs form the most economical means for meeting the losses of the navigation. In low alluvial plains, situated in large basins of the older and more impervious strata, and in some portions of the rocky districts through which the summit-level is carried, it is very common to meet with springs of great abundance. In the former case their overflowings may be advantageously employed in the lower levels of the canal: in the latter, it may often admit of deliberation whether it would not be more economical to execute the summit-level in tunnel, so as to be able to meet and employ the springs which so frequently occur in the interior of the hills to be traversed. Such questions again require an intimate knowledge of Geology.

In some cases the depth of the summit-level pond has been increased for the purpose of making it serve as a reservoir. But Telford justly objects to this course, on the ground, that inasmuch as the level of the lock-sills must be established with reference to the lowest state of the water, every time a lock is filled it causes a waste; and it therefore appears desirable to make the bottom level of the reservoir at such a height above that of the canal as to allow of its waters flowing easily into it whenever a deficiency is felt from any cause whatever.

The section and the fall to be given to a feeder must be calculated upon the formulæ which regulate the calculations upon the flow of running water. In practice, however, it is usual to maintain the fall between the limits of from 1 to 5 in 10,000, unless the peculiar position of the streams which supply the feeders be such as to

require an increase of velocity; and it is obvious that in order to furnish equal quantities, a slight fall requires a larger section, and is objectionable, because it is more exposed to evaporation and to filtrations. A sharp fall gives too great a velocity to the stream; it is likely to injure the banks, and especially to carry down troubled waters into the basins.

Navigable Feeders.

36. If the feeders are intended to be used for the purposes of navigation, a condition which often arises in France and America especially, their dimensions must be regulated with reference to the boats they are to receive. Their fall must, however, not be more than is necessary to give the waters a velocity exceeding 12 to 14 inches per second.

The same precautions alluded to for reservoirs require to be taken with the feeders, in order to prevent their supply exceeding the wants of the canal. Waste-weirs and regulating-sluices must be formed to control the flow; and if the feeders be upon a hill-side, catch-water drains must be formed, so as to allow the mountain streams to deposit the mud they hold in suspension before flowing over into the feeders. It is also recommended to form settling reservoirs from distance to distance in the bed of the feeder itself.

Bed of the Canal.

37. The longitudinal section of the different portions of a canal should be made with a gentle fall, to allow the water to flow with sufficient freedom to compensate for the loss occasioned by passing boats through the locks, or in case it be advisable to leave the bed dry. On some parts of the Erie Canal a fall of 1 inch in a mile was given, whilst in others it was reduced to one-half that inclination: the consequence was, that great vigilance was required to maintain the level of the water when the navigation was active.

Dubuat's formula for ascertaining the proportions of the section of a canal, $R = r \frac{8 \cdot 4}{\frac{S}{S'} + 2}$, in which R = the resistance in a canal; r = the resistance in any undefined fluid; S and S′, the transverse sections of the canal and of the boat,—would require, supposing R and r to be equal, that S were six times S′. In practice it is, however, usual to make the bottom, or floor-line, of a canal twice the width of the boats it is intended to carry, with an allowance of from 6 to 8 inches play on both sides. The lowest basins, or any intermediate ones where boats are likely to be stationed, require to be widened out according to the nature of the traffic. Sometimes in expensive rock-cutting, or in tunnels, the canal is only made wide enough for the passage of one boat at a time; in such cases the canal must be widened out immediately before arriving at the narrow part. Such extra width must also be given at any sharp curve or sudden change in the direction.

The depth of water must be from 1 foot to 18 inches more than that of the deepest laden barges; because, firstly, the bottom is liable to silt up, and secondly, numerous aquatic plants quickly take root. Such extra depth is also necessary for the compensation required by the lockage of the boats.

The sides of a canal, partly from the shape of the boats, and partly from the nature of the materials of which the banks are formed, have an inclination which may vary from 1·5 to 3 in 1. At the water-line it has been found necessary to make a species of banquette, to break the force of the waves or the shock of the boats, upon the edge of the towing-path. Such banquettes are planted with aquatic plants (the iris, reeds, &c.), to increase their retarding action upon the waves. Another method of guarding the towing-paths is to line the sides with stone pitching: on one occasion cast-iron plates were employed for this purpose.

Towing-paths. 38. Towing-paths should be kept much as before explained; and if the hauling be done by men, the width need not exceed from 4 to 6 feet. When horses are used, it should be from 12 to 16 feet wide: the latter dimension is the one adopted on the United States' canals.

Occasionally the action of the winds may be such as to render it necessary to tow from both sides, to prevent the boat from 'hugging' one bank. In such cases a double towing-path is required, of the same dimension as the normal one. At all times, however, it is advisable to construct a narrow footpath on the opposite side, varying from 4 to 6 feet in width. Should there be any excess of earth from cuttings or excavations, it should be employed in widening out the above paths. The towing-path itself should be made with nearly the same perfection as a carriage-road; and in cases where fly-boats travelling at great speeds are used, the maintenance of these paths becomes a matter of serious expense. When the towing-paths are in deep cuttings, a side-ditch must be formed to carry off the rain-water. In embankment, its form and the slope to be given to its external edge must depend upon the materials employed.

Tunnels.

39. When the cutting required to maintain the level of a canal would become too expensive from the mass of earth to be removed, or when there is a probability of meeting copious sources of water in the interior of a hill, tunnelling should be adopted. On some occasions Engineers have preferred to diminish the width of the cutting to merely that required for the passage of a single boat, rather than to execute a tunnel; but local circumstances modify all these questions to such an extent that it is impossible to lay down any invariable rule. Usually, however, if the depth of the cutting be above 50 feet, especially if it be long, there is economy in adopting a tunnel in preference to an open cutting.

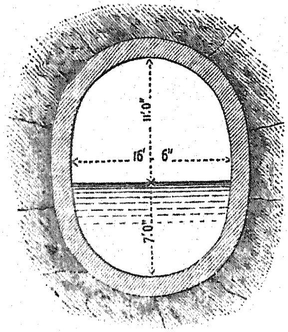
The economy of executing a deep cutting for the passage of only one boat is, comparatively speaking, insignificant; for the bulk of the earth removed in such cases is that required to throw out the slopes. The quantity saved is, in fact, only that occupied by the diminished width multiplied by the depth. With a tunnel, however, the expense is diminished in a much more important proportion, for it is relative to the area. The larger a tunnel is, the more difficult are the excavations; the more necessary is it to line throughout, and the more expensive is such lining. At the same time it must be observed, that in addition to the time lost by the boats waiting their turn at either end, small tunnels offer serious impediments to the navigation on account of the resistance of the air and the water.

Whether the tunnel be executed for one or two boats at a time, it is usual to give about 2 feet play on each side. On the Canal St. Quentin there are two towing-paths 4 feet wide; but it is preferable to make only one of double that width. In the tunnel executed for the Thames and Medway Canal, and in the Harecastle Tunnel, there is only one towing-path, but of rather smaller dimensions than is desirable. Generally speaking, the boats are drawn through tunnels by men, although horses are occasionally used, in which case the towing-path must be made wider, and a parapet formed. In some tunnels executed by Brindley it is necessary to pass the boats by 'leggers,' a class of men who propel them by pushing against the tops and sides of the roof with their feet, whilst lying upon their backs. In other tunnels the bargeman draws the boat himself by means of a tow-rope fastened to the opposite end; in others, again, there are machines fixed at the ends to haul the boats through.

The height given to tunnels, where boats without masts have to pass, varies from

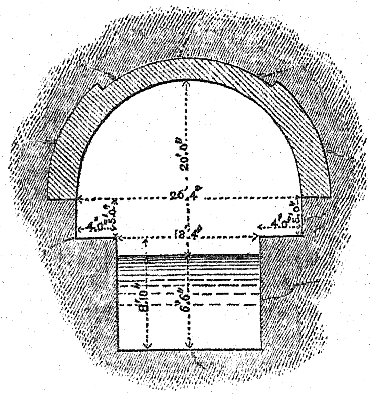
11 to 16 feet from the top of the water to the intrados of the vault. On the canal from the Chesapeake to the Ohio the height was made 17 feet 3 inches, to allow the passage of the sloops and river-craft.

Fig. 15.



Blisworth Tunnel.

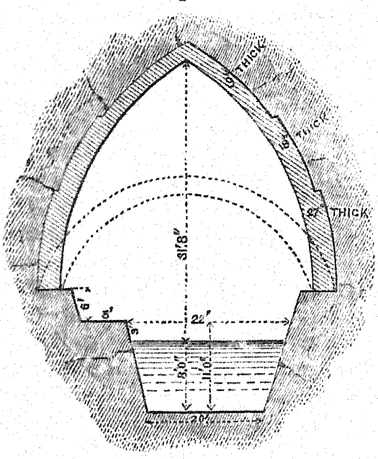
Fig. 16.



Tunnel, Canal of St. Quentin.

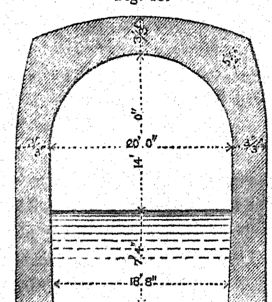
The forms given to tunnels are very various, being either circular, elliptical, or in the shape of a Gothic arch. Sometimes the sides are inclined towards the top, and the intermediate portion joined by a segment of a circle. This form appears to be the best when it is not intended to line the excavation with masonry. Such is, however, rarely the case; for in almost every instance it has been found necessary to resort to that method.

Fig. 17.



Thames and Medway Tunnel.

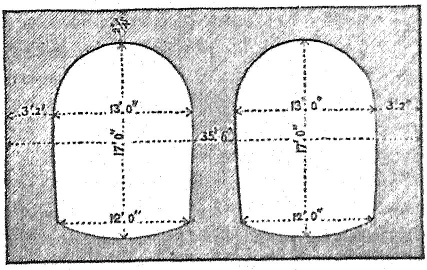
Fig. 18.



Tunnel of the Ardennes.

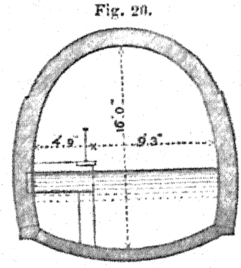
The form of the sides depends upon the dip of the strata to be traversed, and it is usual to make them portions of circles of great radius. The bottom should be an inverted arch.

Fig. 19.



Thames Tunnel.

Fig. 20.



Harecastle Tunnel.

The thickness of the masonry must depend upon the nature of the strata and their permeability to water, as well as upon the materials employed in the construction. Experience appears to indicate 3 ft. 4 ins. to 3 ft. 6 ins. as the extreme thickness requisite in the worst ground and for large canal-tunnels: 2 ft. 6 ins. is the limit for smaller ones. The sides should be made from 6 to 12 inches thicker than the roof.

The cost and time employed upon sundry tunnels in England, France, and America, are stated, in round numbers, in the following Table.

Name.	Canal.	Soil.	Length.	Width, &c.	Time.	Cost per yard. £	s.	d.
Blisworth . .	Grand Junction	Blue clay	3080 yds.	$16\frac{1}{2}$ ft. × 18 ft.	..	17	13	0
Foulridge . .	Leeds and Liverpool	Partly quicksand	1630 ,,	17 ft. × 18 ft.	..	24	0	0
Thames & Medway .	same name	Chalk	$4\frac{3}{4}$ miles	22′ 6″ × 39′ 8″	3 yrs.	32	0	0
Kilsby . .	Lond^{n}. & Bir^{m}. Railway	Earth, sand, water	2398 yds.	.. ..	4 ,,	120	0	0
Harecastle .	Tetney Haven	Clay	2926 ,,	14 ft. × 18 ft.	2 ,,	40	0	0
St. Aignan .	Cn^{l}. des Ardennes	Blue lias	300 ,,	19 ft. × 26 ft.	..	42	0	0
Pouilly . . .	,, de Bourgogne	Schistose marl	3610 ,,	20 ft. × 26 ft.	8 ,,	86	0	0
Comptich . .	.. ..	.. ..	1010 ,,	14 ft. × 18 ft.	..	36	0	0
Charleroy . .	.. ..	.. ..	1400 ,,	14 ft. × 18 ft.	..	52	0	0
Tunnel on canal from Chesapeake to the Ohio.			7330 ,,	.. ..	..	116	0	0

An important observation to be made with respect to tunnels is, that it is preferable to lengthen the tunnel itself, rather than to have a deep long cutting before entering it. The bottom of a valley is usually ill adapted for the commencement of such works, because in such positions it is difficult to keep out the waters of the valley, or to get rid of the land-springs during the construction of the tunnel.

It may be also stated, that in the piercing of tunnels, whenever the length exceeds from 200 to 300 yards, there is an advantage in working from wells, instead of from the ends only. Such wells or shafts are placed from 40 to 100 yards apart, or even at greater distances, depending upon the rapidity with which it is desired to push the works, and the nature of the strata traversed.

Locks.

40. A lock, or pound, is constructed upon a canal for the purpose of connecting two portions which are upon different levels; and in the part called the lock-chamber

the water can be made to coincide with the level of that in either the upper or lower portions of the canal. This is effected by means of two pairs of doors, or gates, one at each end of the lock-chamber; in which gates, or through the side-walls of the chamber, small sluices or paddles are provided, by which water can be let from the higher portion to fill the chamber to the upper level when the lower gates are shut close, or to empty the same to the lower level when the upper gates are closed. It is thus that, supposing the lock-chamber to be at the lower level, a vessel arriving upon the lower portion of the canal enters the chamber, and the lower gates are shut after it. The water is then drawn from the upper level by means of the sluices or gates until it stands at the same height in the chamber as in the upper level; the gates are then easily opened, and the boat passes into the second portion of the canal. When a boat has to pass from an upper to a lower level, the mode of proceeding is the reverse: the gates are shut upon it, and the water is allowed to run from the upper to the lower level. These operations are called 'locking up' and 'locking down.'

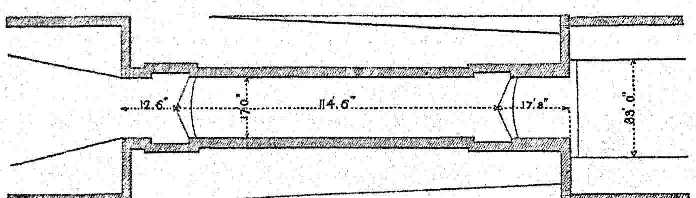
One advantage in uniting several locks in the same locality, so as to facilitate repairs and to concentrate the superintendence, has been already explained. Another reason for such sudden changes in the level of a canal will often be found in the economy they admit in the execution of the earthworks, as by these means either deep cuttings or heavy embankments are frequently avoided. There are, however, certain inconveniences attending the grouping together of the locks in this manner. Firstly, the pressure upon the floor of the lowest chamber becomes dangerously augmented; the tendency to filtration, and to produce upward movements of the floor, is also increased by the same cause. Secondly, such concentrated falls consume more water than would be required if the spaces between each lock were of the average dimensions. But the saving in superintendence, and the eventual economy of time in the passage of the boats, more than outweigh the importance of these objections, especially in such positions as enable the Engineer to command much water, or where the natural form of the ground is very abrupt.

Fall.

41. The number of locks required to compensate any given difference of level must of course depend upon the fall given to each of them. As a general rule, the falls should be made equal, in order to economize water in the passage of boats. At the summit-level, however, there may occasionally be an advantage in making the fall rather less than in the lower parts of the canal, where water is more abundant. Great falls procure economy of time in the passage, and diminish the number of locks to be constructed, and are worked by fewer men. They require, nevertheless, greater strength of construction, and often entail the necessity of extensive earthworks.

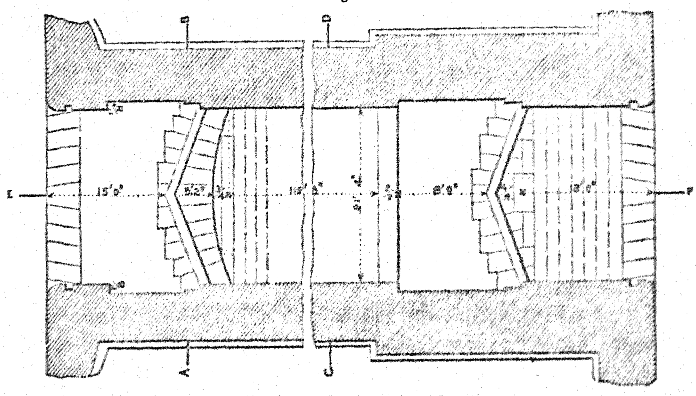
General usage confines the falls of locks between the limits of from 5 to 10 feet for canals having 6 feet deep water: 8 feet to 8 ft. 6 ins. are the usual heights given. Such a lock would require as long a time to pass as a boat would occupy in traversing a distance of one-third of a mile on the ordinary parts of the canal.

Fig. 21.



Locks on the lateral Canal of the Loire.

Fig. 22.

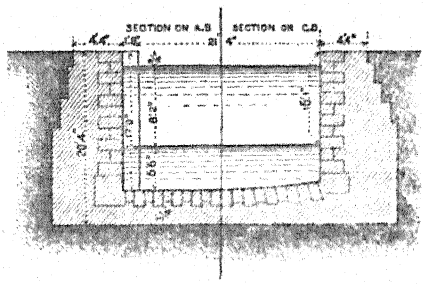


Locks on the Crozat Canal.

Parts of locks.

42. The parts of a lock may be considered as being, firstly, the upper chamber, or head, with its gates, and the breast-wall; 2dly, the intermediate lock-chamber, between the breast-wall and the extreme point of the projection of the lower gates; and 3rdly, of the lower chamber.

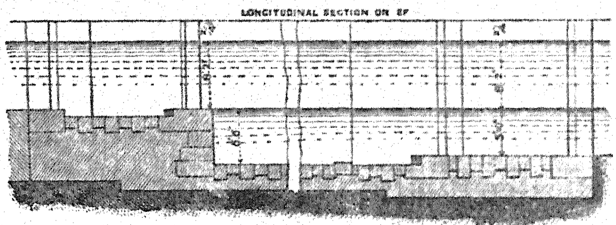
Fig. 23.



Form.

43. On many canals the form of the lock-chambers is made such as to give the side-walls

Fig. 24.



a concave direction towards the water, with the intention of opposing a greater resistance to the pressure of the earth. There does not appear to be anything really gained by this course, because, even supposing the walls do resist the thrust of the embankment more effectually in this shape with the same quantity of masonry, locks so constructed waste more water, and moreover the extra thickness required to be given to the floor on account of the increased span nearly equals the saving in the walls. The best modern canals are made with locks of a rectilinear form, similar to those indicated in the above sketches. Sometimes the sides have been executed in slope, but the loss of water at every passage is enormous, and the prolongation of the wing-walls of both the upper and the lower chambers is often more than enough to compensate for the small saving of the side-walls, especially

when the danger of filtrations is taken into account. From these considerations it has become the practice to make the side-walls vertical.

Wood Locks.

44. In Holland and in the United States, lock-chambers have been frequently executed in wood, on account of the high price of masonry. But such works have a very limited duration, and are hardly ever water-tight. In our own Colonies it may sometimes be advisable to adopt the same method, from motives of economy; but it must only be considered as a temporary substitute for a better material. Details of some American wooden locks are subjoined.

The top of the side-walls of locks should be kept 2 feet above the maximum water-line.

Coffer-dam Grooves.

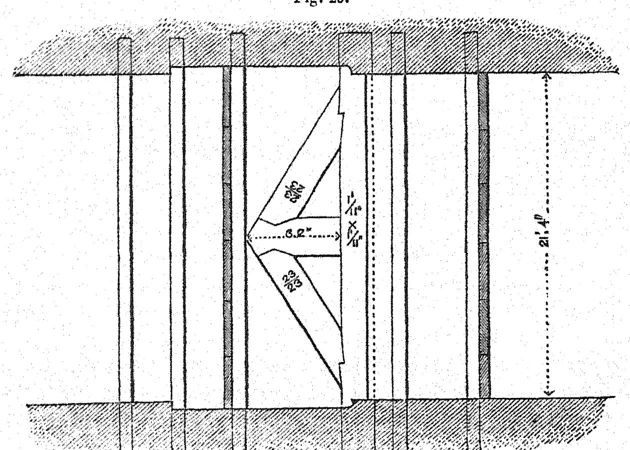
45. To allow means of repairing the works of locks, it is usual to form grooves in both the upper and lower chambers to receive a dam to be thrown across temporarily. Such grooves are made about 8 inches by 8 inches, and of the whole height of the side-walls; they are usually placed from 2 to 4 feet from the returning of the side-walls. A reveal is to be formed to receive each leaf of the gates, about 4 inches deeper than their thickness, and 6 inches longer than the leaves themselves. In order to protect the gates when shut back into these reveals, the side-walls must be carried from 6 to 7 feet beyond them on the upper side; and on the lower, the tail-wall should be prolonged according to the width of the opening. Thus for a 15-feet lock, it should be prolonged 12 feet; for an 18-feet lock, 14 feet; for a 20-feet lock, 16 feet; and so on.

Side-walls.

46. In calculating the thickness to be given to the side-walls, the backing must be regarded as a semi-fluid denser than water, and the mass of the walls must be sufficient to resist its momentum. Some Engineers make them equal in thickness to half the height; but the usual practice varies between 0·28 to 0·50 of that dimension. It would appear that 0·40 is the most rational. It is advisable to strengthen the walls below the tail-gates; and when a lock is joined to a dam, as in river navigation, the end-wall to the stream must also be strengthened, in order to resist the weight of water and to prevent filtrations.

The floor of a lock is usually executed with an invert, to resist the upward thrust of the filtrations from the upper level of the canal. It is usual to calculate its thickness upon the supposition that it would be exposed to an effort equal to that produced

Fig. 25.



Wood floor of old Lock on the Crozat Canal.

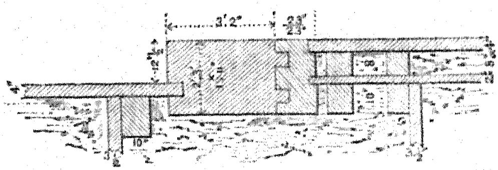
by a head of water equal to the total depth of the lock. The usual thickness given to the floor of a 16-feet wide lock is 2 feet 8 inches; that for a 20-feet wide lock is 3 feet 4 inches. But whatever thickness be given, precautions must be taken to prevent filtrations from the upper level, by either driving a row of close piling, or by stepping the foundations below the level of the ordinary parts of the chambers, so as to break the thread of any stream which might work through.

Sills.

47. The sills are laid with a sally to the upper level of from $\frac{1}{6}$th to $\frac{1}{3}$rd of the width of the opening. The most ancient locks were all made with sallies of $\frac{1}{3}$rd to $\frac{1}{4}$th; modern practice ranges between the limits of $\frac{1}{5}$th and $\frac{1}{6}$th. Professor Barlow states, that the best proportion would be between $\frac{1}{6}$th and $\frac{1}{5}$th, or such as would correspond with an angle of 19°·24.

The sills are raised above the level of the floors of the upper and lower chambers respectively, to form a projection against which the gates are to shut. It is usual to secure the masonry of the body of the sills, and to protect their external edges by means of either wooden or cast-iron clapping-sills, which receive the shocks of the gates. Felt should be placed between the clapping-sills and the masonry. The

Fig. 26.



projection of the sills varies from 10 inches to 1 foot, so as to allow the gates to bear for a depth of from 5 to 6 inches, and to afford the same play underneath. The masonry at the back of the clapping-sills is usually executed as a portion of an arch abutting upon the side-walls. Occasionally the whole of the sill is executed in wood-work, as in figs. 25, 26.

Breast-wall.

48. The breast-wall is usually made concave to the lock-chamber, in order to economize masonry, and to receive the prows of boats while between the gates. Formerly the breast-walls were executed in a perfectly vertical position, and their horizontality with the top of the upper clapping-sills and chamber carefully preserved. Of late years, the upper portion of the breast-wall has been made with an incline towards the lock-chamber, and the face has been disposed with a concave front towards the same direction, so as to break the fall of the water from the sluices in the gates. It is usual to give a thickness of from 2 to 3 feet of masonry behind the sills, whatever be the mode of finishing the wall. Care must be taken that no parts of the masonry project, to catch boats during their passage through the locks. The same observation applies to the coping of the side-walls, which must be made flush with their vertical faces.

In some modern locks, breast-walls have been suppressed altogether. The upper level of the canal is deepened with a gradual inclination to the upper chamber, and the first pair of gates is made sufficiently high and strong to resist its pressure. The economy of this system is more than questionable, and the management of the gates much more difficult than in common locks.

The grooves in which the heel-posts of the gates work, the floor they traverse, and the clapping-sills, are the portions of the fixed work of canals which require the greatest possible care in execution. In some cases they are all executed in dressed stone, or ashlar; in others, in wood of the hardest and best description; in others,

Fig. 27.

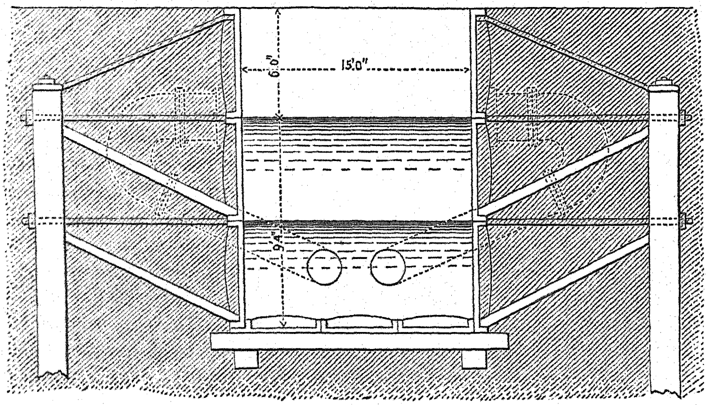
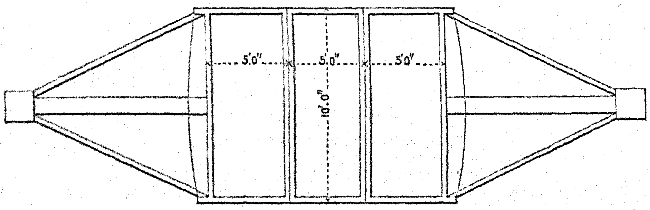


Fig. 28.



Cast-Iron Locks.

again, in cast iron. It is indispensably necessary that the fitting of the posts should be perfectly water-tight, and that friction at the bottom of the gates should be prevented.

49. On the Ellesmere and Chester Canal, Telford executed some of the locks entirely in cast iron, upon foundations of little better than running sands. They answered admirably in such positions, but the first cost was necessarily very considerable. Perhaps, in such positions no other system could have succeeded at all, with the exception of wood locks, but these have the serious inconvenience of early decay.

Owing to the agitation produced in the lower chamber by the escape of the water through the sluices, it is advisable to prolong the floor into the bed of the canal, for a distance of 40 feet, for an ordinary fall of 8 feet in the lock. The entry to the upper chamber is also frequently paved to about the same distance, in order to prevent the excavations which might be occasioned by the increased velocity given to the water at the upper gates.

Lock-gates.

50. For the most important canals, the lock-gates consist of two leaves, fitting close, and bearing against the sills at the bottom as well as the grooves in the side-walls. They are generally made of wood; but of late years many gates have been executed in cast or even in wrought iron, or in a compound system of cast and wrought iron and wood. (See Plates II. III. IV. and VII.)

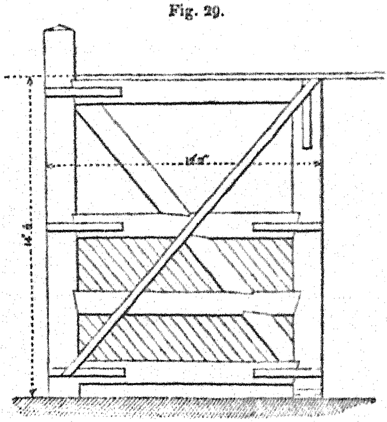
The gates are composed of the upright posts, the turning-post being known as the 'heel-post,' and the meeting one as the 'mitre-post.' These posts are united together by horizontal rails, which support the pressure of the water, and are variable

in number according to the height of the gate. Against these rails the planking or wrought-iron plates, which close the gates, are fastened.

The posts are kept about 2 inches clear of the floor, so as not to bear immediately upon it in their revolutions; they are made from 8 inches to 10 inches above the water when the gates are opened by machinery, and somewhat longer when that operation is performed by a long lever on the top of the gates. The lowest rail is usually placed 4 inches above the floor; the upper rail finishes about 4 inches above the maximum water-line. The intermediate rails are spaced according to the effort they have to resist. A raking brace is introduced between the rails when the span is great, and a wrought-iron tie joins the foot of the mitre-post to the top of the heel-post, to prevent the frame-work from giving at the foot. As the load of the water in a lock presses with greater weight at the bottom than at the top, it follows that the lower rails must be kept closer together than the upper ones, so that the resistance may augment with the effort. In the gates for a lock 17 feet wide with an 8-feet lift, it is usual to make the posts and top and bottom rails of the lower gates about 12 inches deep by from 11 to 12 inches wide; the four intermediate rails are about from 10 inches deep to from 9 to 11 inches wide. The upper gates are made with posts and top and bottom rails 11 inches square; the one or two intermediate rails being in proportion. The tenons have one-third the width of the rails, and enter the post to half its thickness.

When the gates are planked, the least thickness that can be given is 2 inches, or it would be impossible to caulk them. Sometimes the planking is applied horizontally, sometimes diagonally. To obviate the effects of any obstruction in the bottom of the chamber upon the solidity of the framing, it is usual to let in wrought-iron squares, flush with the wood-work, and bolted through at the meeting of each rail with the upright posts. These squares are of iron, from 2 to 3 inches wide by

Fig. 29.



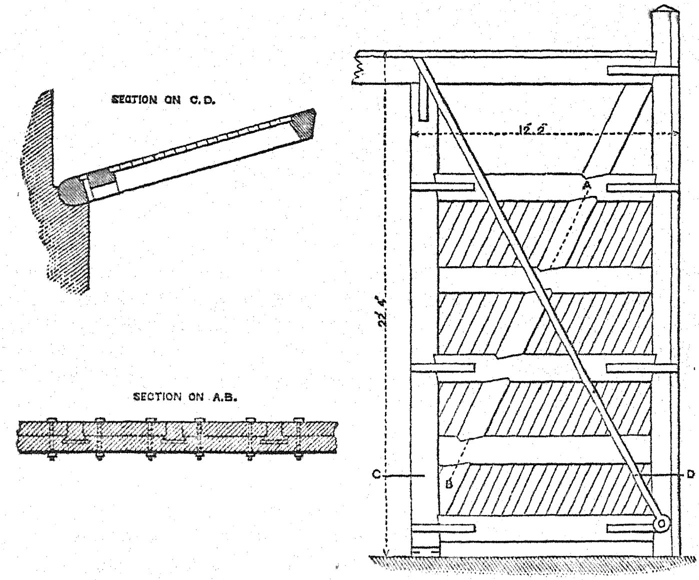
Elevation of Upper Gates.

from $\frac{1}{2}$ to $\frac{3}{4}$ inch thick; the tie from the foot of the mitre to the top of the heel-post is of iron, from 5 to $6\frac{1}{2}$ inches wide by from $\frac{3}{4}$ to $1\frac{3}{8}$ inch thick.

It is important in setting out the frame-work of lock-gates to keep the unsupported extremity about 2 inches higher than it is required to be in execution. This difference will barely compensate for the shrinking of the framing.

The heel-posts turn upon a metal pivot, working in a metal socket; the former being let into the floor of the chamber, and the latter into the post, which must also

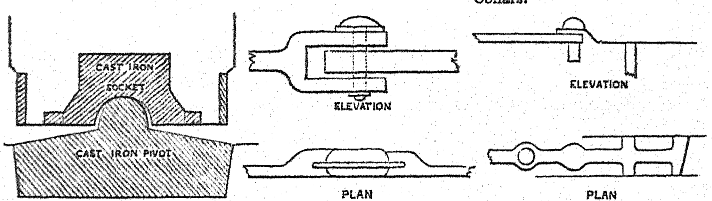
Fig. 30.



Elevation of Lower Gates.

Fig. 31.

Collars.



be shod with a wrought-iron hoop. In some of the ancient locks the socket was in the floor, and the pivot upon the heel-post; but it was found that the mud in the canal choked up the socket very rapidly. The upper part of the heel-post turns in a collar, made with hinges, and secured into the land by a set of long wrought-iron anchors let into the masonry. If the posts do not mount for the purpose of receiving levers, they may work at the top upon a pivot concentric with the lower one. The size of the collars is usually from 3 to 4 inches wide by ¾ to 1¼ inch thick; the land-ties, or anchors, are 5 feet long by from 1½ inch to 3 inches square, with tieing-down bolts 3 feet long.

Mr. Barlow recommends that in large lock-gates the leaves should present a curvilinear section in plan, because such a form presents a greater resistance for the same cubic quantity of wood. Theoretically the best form appears to be that resulting from a portion of a circle passing through the points found by the pivots and the sally of the sill. He further recommends that in practice the form of a Gothic arch should be preferred, making the apex from 1 foot to 18 inches beyond that of the circle so ascertained. The objection to this form of gate is, that it is difficult to find

wood with a natural curvature suitable for the purpose. When cast or wrought iron is used, this form should be adopted.

Sometimes, when the gates are of great height, they are made in two portions, to facilitate the opening. It has also been proposed to execute a portion of the upper part with hinges, to allow of its being thrown down towards the end of a lockage, for the purpose of expediting the operation of filling the chamber.

Sluices.

51. The water is passed from one level of the lock to the lower one by means either of sluices formed upon the gates themselves, or by small culverts passing from one level to the other, or by syphons. The usual proportion of the water-way of the sluices is about 0·002 to 0·013 of the surface of the chamber. Formerly the sluice-valves used to be executed upon the gates themselves, and the whole was in wood. This was found to augment the thickness of the gates to be lodged in the side-walls to an inconvenient extent, and latterly both the gates and their frames have been executed in metal.

The valves upon the gates should close hermetically, and be easily manageable; they must be as large as possible, to allow of the locks being filled in the shortest possible time, especially during the latter stages of the operation. To fulfil these conditions they must be about 4 feet wide, by from 1 foot 4 inches to 1 foot 8 inches high. In the latest works of this description, whenever the raking brace is suppressed the whole space between the posts is devoted to the opening of the valves. On the Canal du Centre, in France, it was noticed that the water rose 8 feet in 6 minutes, and the last 8 inches alone took 4 minutes more. To remedy this loss of time, on the Canal St. Quentin a folding leaf of 1 foot wide was adapted to the top of the gate, and with tolerable success. But the lock-men in practice expedite the operations by opening the gates when the difference of level is about 6 inches: to do this in a manner not likely to injure the gates, the cord by which they are opened must be fixed at $\frac{1}{3}$rd of the height.

The orifice of the vanes must be placed as nearly as possible in the centre of the leaves of the gates, in order that the jets may meet and destroy their reciprocal effects. They are opened either by a rack and pinion, by an endless screw, or by a long lever. Frequently they are made with a counterpoise, to diminish the friction. The sluice-valves are always placed on the upper side of the gates.

Many instances occur in which the water passes through tunnels from the upper to the lower level; but such a system is liable to the very serious objections of augmenting considerably the quantity of masonry in the first case, requiring more expensive machinery in the second, and finally in being much more likely to get out of order. In fact, the abrupt curves which are necessarily made in such tunnels serve to retain the water and any mud they hold in suspension, and thus cause the tunnel to be rapidly choked up: it is also very difficult to repair or clean them out. Figs. 32 and 33 represent the tunnels used on the Canal de Briare.

Fig. 32.

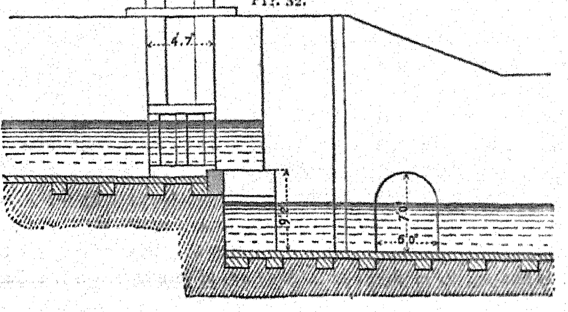
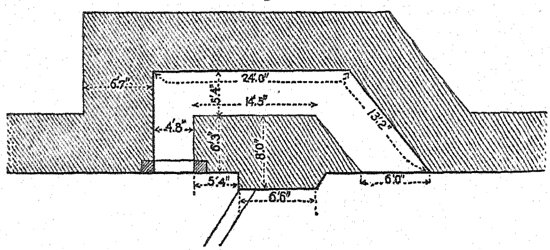


Fig. 33.



An inconvenience attached to this mode of changing the levels of the water in the lock-chamber arose from the fact that the two lateral streams, issuing from the tunnels, impressed an oscillatory movement upon the boats, causing them to strike alternately upon the side-walls. An attempt to remedy this was made by bringing the mouths of the tunnels under the breast-wall. But such a method, although it obviates the lateral shocks, is still objectionable, inasmuch as the strength of the breast-wall is much diminished. Practically, Engineers at the present day have returned to the ancient system of sluice-valves upon the lock-gates themselves, as being the simplest and most economical.

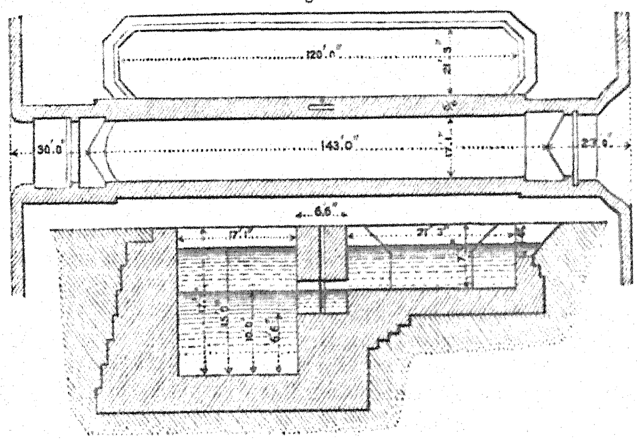
In proportioning the size of the openings of the sluices it must be borne in mind that the effective discharge from them is never equal to the theoretical discharge. Both from the contraction of the fluid vein in the first movements of the flow, and the diminished discharge owing to the smaller head of water at the end, it has been found that the results obtained from theory differ very much from those which occur in practice. When only one sluice is in operation, it appears that the real discharge is only 0·625 of that obtained from the elements furnished by the head of water and the surface of the opening. When two sluices are in operation, the coefficient becomes 0·548. Or the quantity discharged through two sluice-gates, drawing water from the same source, and whose streams meet immediately after leaving the upper level, may be represented by the formula, $Q = m\,S\,\sqrt{2\,g\,H}$; in which m = the coefficient given above; S = the sectional area of the sluices; g = the numerical expression of gravity at the intended position of the lock; and H = the height of the head above the opening.

Accessory Works.

52. In constructing the locks it is desirable to provide mooring-posts at the ends, and towing-rings in the side-walls, to facilitate the movements of the boats. Sometimes ladders are let into the side-walls to allow of visiting and repairing the lower parts of the chambers. Provision of some kind, either by means of a rope stretched across the lock, or by a boom, must be made to prevent boats from striking against the gates whilst waiting to be passed from one level to the other. The entries to the chambers must also be arranged in such a manner as to allow boats to be directed easily into them.

When the navigation is active it is necessary to have two locks side by side, one locking up whilst the other locks down. Such an arrangement enables a considerable economy to be effected in the consumption of water; for if an aqueduct be made between the two, all the water which passes from one to the other is, in fact, economized upon the quantity required from the upper level. In warm dry climates many systems have been introduced to save the water in lockage, an example of which from the Canal d'Antoing is given; but the construction of such works resolves itself at last into a simple question of economy. On the same canal a very admirable system was adopted, which may probably be found capable of more

Fig. 34.



Side-Pond on the Canal d'Antoing.

general applicability. It consisted in the establishment of a double steam engine of 112 horses' collective power, which pumped up the water from the lower level of a series of five locks placed in juxta-position. The water thus passed down through the locks was made to serve a second time at an expense not exceeding 0·00228 of a penny per foot cube. Such a use of steam-power is not, however, cited as a novelty, for many of our own canals employed it largely. Telford appears to have arrived at the conclusion, that the use of side-ponds rather lengthened the operations of lockage.

Pont aux Rouleaux.

The opening of the gates sometimes necessitates the establishment of some machinery upon the platform of the locks, especially when their dimensions are considerable. Small locks are opened either by means of a lever formed by the prolongation of the top rail, or by pushing or pulling the gates with a kind of boat-hook. Larger ones require to be moved by a rope or chain working upon a barrel set in movement by a wheel and pinion.

The communication between the two sides of the platforms of a lock-chamber is usually effected by means of a footpath carried upon the gates themselves, care being taken that no projection be left towards the chamber to interfere with the movements of the boats.

Telford describes a system employed on the Shrewsbury Canal, which may be advantageous in cases where small or short boats are in general use. It consists in so forming the locks as to admit either one, three, or four boats to pass at a time, without the loss of any more water than what is just necessary to regulate the ascent and descent of the boat or boats that are then in the locks. This is accomplished by having gates that are drawn up and let down perpendicularly, instead of being worked horizontally, each lock having three gates.

Inclined Planes.

Substitutes for Locks.

53. In some situations it has been found necessary to adopt a different method of passing boats from the higher to the lower level of a canal than by the use of locks. Such a necessity may arise from a want of water, or from the fact of the natural form of the ground being so abrupt as to make the number, or the fall of the locks, inconvenient. The different means of effecting the object in question have varied in

an infinite degree, but they may be conveniently classified under two heads, viz. balance-locks, or inclined planes.

Telford mentions several descriptions of balance-locks proposed from time to time, for details of which the reader is referred to the 'Repertory of Inventions,' vols. i. ii. and ix., and to Chapman's 'Observations on Canal Navigation.' On the Grand Western Canal a balance-lock of this nature has been executed, by which a difference of level of 46 feet is compensated with a remarkable saving of time and water. It consists of two chambers, with a pier of masonry between them, of the dimensions necessary to receive a case into which the boats are floated. Strong chains pass over a series of wheels supporting the cases, working in the chamber in such a manner that one is kept upon the upper level whilst the other corresponds with the lower one. The quantity of water admitted into the upper case is so arranged as to give it a slight preponderance over that of the lower, sufficient to impress a gradual and easily regulated movement to the machinery. The passage from one level to the other does not occupy more than three minutes, and the consumption of water is about two-thirds of what would be required to fill a lock of the same dimension. The only objection to such a system is its expense, and the difficulty of maintaining it in working condition.

Inclined planes have long been in use, and offer great facilities for overcoming differences of level, when these pass certain limits. In all these cases it is important not to lose sight of the fact, that the applicability of such substitutes for locks is an economical question, in which it is necessary not only to consider the cost of the first establishment, but also that of the working and maintenance. Unless, therefore, the difference of level be very great, there can be no advantage in departing from the ancient system of locks.

54. Telford mentions the construction of a 'pont aux rouleaux' on the canal between Amsterdam and Sardam: this consisted of a set of rollers placed at short distances, over which, by means of a water-wheel, the boats were hove up to the ridge separating the two waters to a point a little higher than the level of the upper one, and were launched down to the other.

55. On the Duke of Bridgewater's subterranean canals one inclined plane was formed 35½ yards high and 151 yards long: the water escaping from the upper chamber in this case served to work the air-pumps of the lower levels of the mines. On the Shropshire Canal there are three inclined planes, respectively of 126, 120, and 207 feet rise, which were completed in the year 1792. The boats are adapted to frames upon carriages made to run upon railroads, and they are set in motion by a steam engine acting upon an endless rope coiled upon a drum. On one of these inclines, 600 yards in length and 42 yards rise, six boats were taken up and six taken down in an hour, the steam engine and three men only being employed. The boats were only of 5 tons each. On the Shrewsbury Canal, Telford executed a plane 223 yards long and 25 yards rise on the same principle.

On the Canal du Centre similar inclined planes have been introduced, on account of the want of water. On the Morris Canal, in the United States, there are no less than fourteen such planes, each about 100 to 102 feet high, with an inclination of 4 feet base to 1 foot in height. M. Betancourt indicates as the limits of inclination a range between 8° and 25°, or from 7 to 46 in 100.

On the Duke of Bridgewater's Canal the consumption of water for the passage of a boat is only equal to about one-half a lockful, whilst the ordinary system would have required no less than from 28 to 30 times that quantity. The boats are run into a lock at either extremity, and the whole case traverses the inclined plane to the lower level, where the boat floats into the ordinary part of the canal. On the

Shropshire inclines they are simply let into carriages, which are subsequently carried over a summit closing the end of the canal, and then let down into it. On the Morris Canal the locks themselves traverse the planes, so as to maintain the boats constantly floating during the passage. Each lock is 50 feet long, 9 feet wide, and 3 feet deep, and contains 45 tons. It rests upon a triangular frame running upon rollers, weighing, with the empty lock, 15 tons, or 60 tons when full. The boats usually weigh, loaded, 25 tons. The cost of the construction of this series of planes upon the Morris Canal was only half that requisite for a set of locks able to produce the same result, as far as compensating the difference of level is concerned: the economy of water is therefore a pure gain.

Over-Bridges.

56. When it is necessary to erect bridges over canals, the height from the water-line to the under side of the arch should not be less than 13 feet, if the locks are 17 feet in width. If constructed to receive large boats, and the locks are 26 feet in width, it is preferable to augment the height to 18 feet. The water-way should be from 1 foot 4 inches to 2 feet wider than in locks, for boats do not stop to pass through them, as in the latter case. A bridge should be placed in such a position that the canal be in a straight line above and below it for about 200 or 300 yards.

On the Dutch and Belgian canals it has been found necessary to execute many swivel or lifting bridges, to carry roads over the canals. Such erections are very costly, and they entail considerable expense for maintenance and management. If therefore they can be avoided, and permanent works substituted for them, it is very desirable. The rules which regulate the construction of canal-bridges are equally applicable to all similar works: the reader is therefore referred to the articles 'Bridges,' and 'Passage of Rivers.'

Culverts and Aqueduct Bridges.

57. In traversing a line of country of any length, especially in mountainous regions, streams holding much foreign matter in suspension are frequently to be diverted, so as not to discharge their waters into the canal. Such streams may be encountered at different levels, either above or below the water-line of the canal, requiring a different system of construction in either case.

If the level of the stream be much above that of the canal, the simplest mode of dealing with it is to carry the aqueduct at once at the higher level. But such a case rarely occurs, and the streams mostly are but little removed from the level of the canal, rendering necessary the construction of a syphon or a straight culvert. Such culverts are simple enough; but the syphons are difficult to repair, and they very soon choke up if the waters brought down by the stream be at all troubled. They should only be used for very limpid waters, and settling reservoirs should be formed before the entry of the syphons.

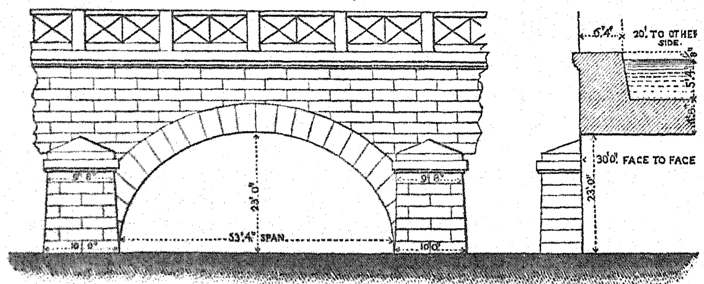
When, however, the stream assumes any considerable dimensions, it is necessary to carry the canal over it by a bridge, the form, nature, and expense of which depend on the size of the river to be traversed. Such a bridge, in addition to the ordinary difficulties attending the construction of similar works, becomes more difficult from the necessity of rendering it water-tight. Leakages, in fact, compromise the solidity of the works in the same proportion as they entail a loss upon the water in the canal. For small bridges, this object may be effected by lining the bottom of the bed with lead or zinc; for larger works, such a course is not applicable, and the bridge itself must be made to retain the water.

The width of the waterway in a bridge aqueduct need not be more than 8 inches

on each side than the widest boats likely to traverse it, or, in fact, a little more than that of the locks upon the same canal. Only one towing-path is absolutely necessary, although it is usual to execute two: if for men, 3 feet is sufficient; if for horses, they should be 6 feet wide.

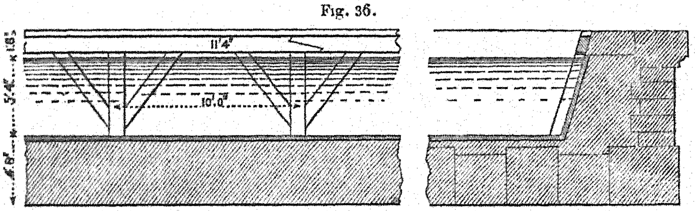
When the bridge is executed in masonry, the actual bed of the canal should not be constructed until the centres have been struck, and all settlements have taken their full effect. The bed should be executed in concrete, made very carefully with the best hydraulic lime; and it is a very necessary precaution to form, in the haunches of the arches, aqueducts to carry off the waters which might filter through. When the bed is executed in masonry, care must be taken to coat the intrados of the arches with either asphalt or concrete, and the inside of the masonry must be pointed and rendered with a hydraulic cement. The water must be introduced as soon as possible, in order to prevent fissures from the sudden drying of the lining.

Fig. 35.



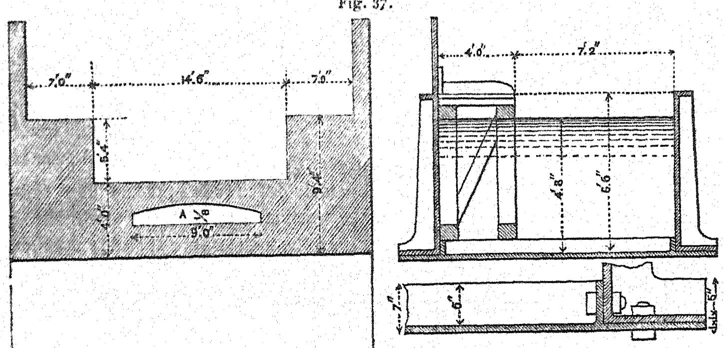
Aqueduct of Digoin.

Fig. 36.



Trough shewing timber-guards, Digoin.

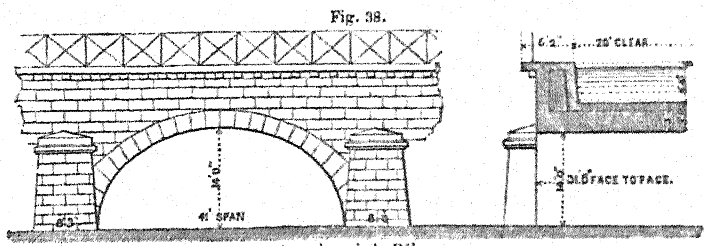
Fig. 37.



Union Canal. Scotland.
A, warm-air flue.

Cast-Iron Aqueduct, Ellesmere Canal.

Fig. 38.



Aqueduct de la Bébre.

58. The aqueducts of Digoin and of the Allier, executed under the orders of M. Julien, are perhaps the most carefully executed works of this description erected of late years. That of Digoin is 810 feet long, and consists of eleven arches; that over the Allier is 1298 feet long, with eighteen arches, and three locks comprised in the prolongation of the wing-wall on the down side. The first aqueduct cost about £192 per metre, or £172 per yard; the second cost £296 per metre, or £266 per yard.

On the aqueduct for the Union Canal, in Scotland, a warm-air flue was introduced to prevent the injurious effects of the frost. (See fig. 37.)

On the Ellesmere and Chester Canal, Telford constructed one of the most remarkable and original works which he ever executed, to carry the canal over the valley of the Dee. It consists of an aqueduct 1007 feet in length by a maximum height of 127 feet. The piers are about 45 feet apart from centre to centre, by 7 feet 6 inches wide, and 13 feet broad at the top. The trough is formed of cast-iron plates, supported upon four cast-iron arched beams of 7 feet 6 inches chord to the intrados, well cross-braced and tied together. The towing-path is supported in such a manner as to allow the water to flow freely under it. The side and bottom plates are firmly bolted and riveted together. The total expense of this truly wonderful work was £47,018, or about £141 per yard; and, considering the boldness of its conception, the skill with which its details were carried out, and its moderate cost, the superior attainments of this eminent Engineer must be admitted.

In the United States, where wood is cheap, and masonry or iron-work excessively dear, aqueducts have been executed in carpentry. The most remarkable work of this kind is that which carries the Canal of Alexandria across the Potomac at Georgetown. It is about 1077 feet long between the abutments, and has nine arches. The piers are about 7 feet 2 inches wide at top, with a batter of $\frac{1}{12}$th on each side, and they receive the trough at a height of about 29 feet above high-water mark. Three of the piers, however, are of an extra width, so as to form intermediate abutments; they are made 12 feet 10 inches wide at the top. The length of the ordinary piers is 41 feet at the summit; measured upon the cut-water, at high-tide level, they are 47 feet 6 inches. The trough was executed in wood-work, upon Town's system, with double lattice on each side, 18 feet 8 inches deep. (See Plate V.)

There are numerous inconveniences attached to the erection of bridge aqueducts, which should lead the Engineer to prefer carrying the canal in embankment, even at an increased expense, if there be no insurmountable difficulty in so doing. The diminution in the width of the canal renders the traction more difficult; much time is lost by the boats being forced to wait their turn; the maintenance is always a source of great outlay; and, lastly, the great cost of such erections often leads to lowering the canal on one side to rise again on the other, in order to save the height of the piers. If, however, the erection of a bridge aqueduct be inevitable, it is necessary, in addition to the precautions already mentioned, to place waste-weirs above the entry, so that, in case of flood, water may not fall over the sides of the embankment.

Meeting a River on the same Level.

59. Many of the affluents of the rivers which run in the valleys whose direction a canal follows must occasionally cross it at the same level. If they be not diverted and passed under the canal, but made use of for its supply, care must be taken to form settling reservoirs, and a dam with proper sluices to regulate the quantity of water to be admitted, and to destroy the velocity it might have acquired in its natural flow.

When the stream is, however, sufficiently large to be navigable, it is necessary to construct such a system of locks as to be able to close either navigation which may not be required; the normal position of the locks being such as to maintain a constant level of water in the canal. The great danger to be feared in cases of this description is, that the streams may bring down foreign matter to choke the bed of the canal.

On the Canal du Midi an ingenious system for closing the bed of a torrent at the time of floods was introduced. It consists of a pontoon, one side of which is fixed vertically, and the opposite side is made with a hinge. At the time of floods this pontoon is floated to the mouth of the torrent, and the hinged side is let down, the vertical one forming a dam. When the floods are over, the side is raised and the pontoon floated away. It is maintained in its position by walls in masonry at the intersection of the stream with the canal.

An example of a canal meeting a navigable river is given in the Plates.

Supply Valves, Waste Weirs, and Supplementary Works.

60. The introduction of water into canals is effected by means of conduits, which are regulated by gates whose openings are proportioned to the wants of the navigation. The nature of these works varies so much with the nature of the supply of each particular canal, that no general rule can be laid down for their construction. They must of course be large enough to admit the flow of water with tolerable rapidity, in order to fill the canal with the least possible loss of time after it has been laid bare.

Waste-weirs must also be provided in each long reach of a canal, sometimes with a channel to lead the surplus water into the natural discharge of the surrounding country. In other cases the surplus water may be allowed to fall over the lock-gate or be led by a tunnel to the lower level. Care must however be taken that no cataract be formed in positions likely to injure the solidity of the works, and that the waters be not allowed to have a dangerous velocity at their place of discharge. Mr. Thom introduced upon the conduits leading water to Greenock several systems of self-regulating sluices, which might be advantageously applied upon canals.

Safety-gates have been occasionally used, which serve to close the canal when a current is formed in any particular direction by a fissure of any kind. They are, however, of doubtful utility, for they hardly ever act efficiently in cases of need.

Outfalls must be provided in each long reach of canal, to allow of its being laid dry for repairs or examination. Indeed, as this suspension of the navigation must take place once a year on account of the deposit of mud, or the development of the aquatic plants, it is important that it should be effected with the least possible loss of time.

Junction with Rivers, and Termini.

61. The termination of a canal in a river usually requires a double lock to maintain the level of the waters, either against the upper or under stream, especially when the embouchure is partly exposed to tidal action. It is advisable that

such locks be preceded by a basin or dock of sufficient dimensions to allow sea-going vessels to enter simultaneously with barges; and in such cases it is usual to provide a set of lock-gates to close the end of the canal which joins the basin. An excellent example of such a basin exists at the terminus of the Regent's Canal.

In ordinary cases the entry into a river must be placed on the concave bank, to avoid the destructive action of the stream; but as deposits take place on the concave sides, means must be provided to scour the passage to the locks. The entry must be above any affluent which might be in the neighbourhood; and its direction should form an acute angle with the stream of the main river, as was observed under the head of 'River Navigation.' The upper jetty should project into the stream so as to render the water in the entry perfectly still; the lower one should join the bank with an easy curve. Mooring-posts and guard-booms should be provided at the entries, to facilitate the movement of the boats, and to guard the lock-gates from the shocks of the vessels.

The first lock should be placed, at least, one clear boat's length from the extremity of the normal line of the bank on the up-stream side. Basins must be formed both at the termini and at the intermediate dépôts, as also such roads, sheds, machinery, and offices as the nature and importance of the navigation may require.

Fences and Enclosures, &c.

62. Lastly, it is necessary that a canal be carefully protected from injury by trespassers, or by the cattle in country districts, by means of strong and efficient fencing. Such fences should be backed by a hedge and ditch, for the double purpose of rendering the enclosure more perfect, and of carrying off the rain-water it is considered desirable not to direct into the canal. In the interior of towns, or upon the borders of a highly frequented road, it is often necessary to enclose a canal with a solid wall, or at least with a close-boarded fencing. Basins, or intermediate ports, are especially necessary in such positions as require perfect enclosure, both for the security of the canal itself and for that of the goods transported.

Dépôts must be formed, at convenient distances, of all the materials necessary for the maintenance and repairs of either the bed of the canal or of the works, including under that term locks, bridges, culverts, and aqueducts. It is advisable to have in such dépôts all the materials necessary to form a dam across the canal, in case it becomes requisite to execute on an emergency any repairs which would, without such a precaution, require the canal to be entirely laid dry. Materials for the repair of the towing-path must also be provided at convenient spots.

The dangers arising from the burrowing of moles and rats are so great that it is expedient to have a person specially charged to destroy those animals. But perhaps the best remedy would be to execute a concrete lining to the canal, instead of merely puddling it.

Constant superintendence on the part of the resident Engineer cannot be too much insisted upon. The embankments, bridges, tunnels, locks, lock-gates, bridges, and culverts, are all exposed to injury; but a slight repair in the first instance would often save immense outlay in the end, and it is but bad economy to endeavour to dispense with skilful superintendence.

Statistics.

63. A statistical account of the canals in different countries would far exceed the limits of this article: the following statement will, however, indicate the commercial importance of the subject, and serve as a guide to the Engineer in forming approximative estimates of the cost of similar works.

In England, according to Mr. G. Rennie's Report to the British Association, in the years 1838 and 1839, no less than 2277 miles of canal navigation had been executed up to that period; in Scotland, not much more than 200 miles; and in the whole island of Great Britain, 2236 miles of river navigation had been improved. These figures may be thus grouped in a tabular form:

River Navigation.	Miles.		
England and Wales . .	2036	at a cost of about	£5,000,000
Scotland, about. . . .	200	„	1,269,000
Total	2236	„	6,269,000
Canal Navigation.			
England and Wales . .	2277	„	19,793,065
Scotland, about . . .	200	„	2,344,324
Total	2477	Total . .	£28,406,389

In the United States, up to the year 1837, more than 2000 miles of canal had been constructed, at an average cost of about £4600 per mile.

In France, to about the same period, according to the statistics communicated to Mr. G. Rennie, there were executed for the seven lines of junction between two seas, a length of canal of 3,068,876 metres, at a cost of 306,429,601 f. 50 c. The length of the lines leading to Paris was 1,020,022^{m}·64, at a cost of 143,935,916 francs.

			£.
Thus in England the cost per mile has been			9,000
„ Wales	„	„	5,000 to 6,000
„ Scotland	„	„	11,000
„ France	„	„	8,030
„ the United States		„	4,600

Maintenance. 64. The maintenance of the New York canals cost, up to 1837, no less than £180 per mile; that of the Ohio canal, £64. On the French canals, the maintenance has varied from £60 to £87 per mile.

Detailed Costs. 65. It may be estimated with tolerable safety that the average cost of canals is about £4 per yard, with an addition of about £1000 per yard of the fall of lockage. Each lock, on an ordinary canal, costs about £3000. On the Caledonian canal, where the locks are 170 feet long by 40 feet wide, and 8 feet fall, the cost was about £6000 per lock.

The waste-weirs for a large canal cost about £1500 each.

Basins and dépôts on the intermediate parts of the line require an additional sum of about £1500 each. Those at the termini vary so greatly in importance that it is not possible to predicate their expense.

Common under-bridges, of not more than 30 feet span, cost about £500 each, on the average. Small over-bridges may be taken at the same price.

It is difficult to estimate the expense of large aqueducts; but, as an approximation, it may be stated that some of the most expensive have cost as much as £2 per yard superficial of waterway, when they have been about 130 feet high.

Working and Tolls.

66. In the working of canals, the expense of loading and unloading the barges may be taken at from 7*d.* to 10*d.* per ton; and the traction and expenses of navigation, upon a well-managed canal, should not exceed 5*d.* per mile traversed by a boat. The tolls must necessarily vary with the number of locks and the first cost of the canal:

they may, however, be assumed as being about the same as the traction, or 5*d.* per mile traversed.

The loss upon the goods transported, owing to the leakage of the boats, is sometimes as much as 1 per cent. on their value; and a similar allowance is commonly made for the pilfering to which the cargoes are exposed.

The principles which have guided the French Legislature in fixing the tolls to be taken by the Companies constructing canals in that country have been to allow a charge of $0^{f}\cdot10$ per ton and per kilometre, or $1^{d}\cdot6$ per ton per mile. Empty boats returning pay only 1*s.* per lock passed.

In the compilation of this article the following works have been consulted:

Chapman's Observations on Canal Navigation.
Telford's Reports, and the article written by him upon 'Canals' in Rees's Cyclopædia.
Sutcliff's Observations on Canals.
Brooks on the Improvement of Rivers.
Stevenson on the Improvement of Tidal Rivers.
Fairbairn's Remarks on Canal Navigation.
George Rennie's Reports to the British Association.
Scott Russell's Reports to the British Association.
Colonel Vallancey's Treatise on Inland Navigation.
Colonel Phillpotts' Report on the Canal Navigation of Canada.
The Parliamentary Reports on the Irish and Colonial Works.
Strickland's Public Works of the United States.
Cressy's Encyclopædia of Engineering.
Somerville's Physical Geography.
Lyell's Geology.
Sganzin, Cours de Construction.
Huerne de Pommeuse, des Canaux Navigables.
Pillet-Wille, de la Dépense et des Produits des Canaux et des Chemins de Fer.
Poussin, Travaux d'Améliorations Intérieures des États Unis.
Michel Chevalier, Histoire et Description des Voies de Communication aux États Unis.
Nadault de Buffon, des Canaux d'Arrosage de l'Italie Septentrionale.
Claudel, Formules à l'Usage des Ingénieurs.
D'Aubuisson, Traité d'Hydraulique.
Architecture Hydraulique de Belidor, édition de Navier.
The works of Hachette, De Prony, Venturi, Bidone, Michellotti, Poncelet, Lesbros, Castel, Bossut, Dubuat, Mariotte, Bernouilli, and Eytelwein, upon Hydraulics and Hydrostatics.
Morin, Aide-Mémoire à l'Usage des Officiers d'Artillerie.
Andréossy, Histoire du Canal du Midi.
Girard, Histoire du Canal de l'Ourc.
Genieys, Essai sur les Moyens de Conduire et de Distribuer les Eaux.
Annales des Ponts et Chaussées des Mines.

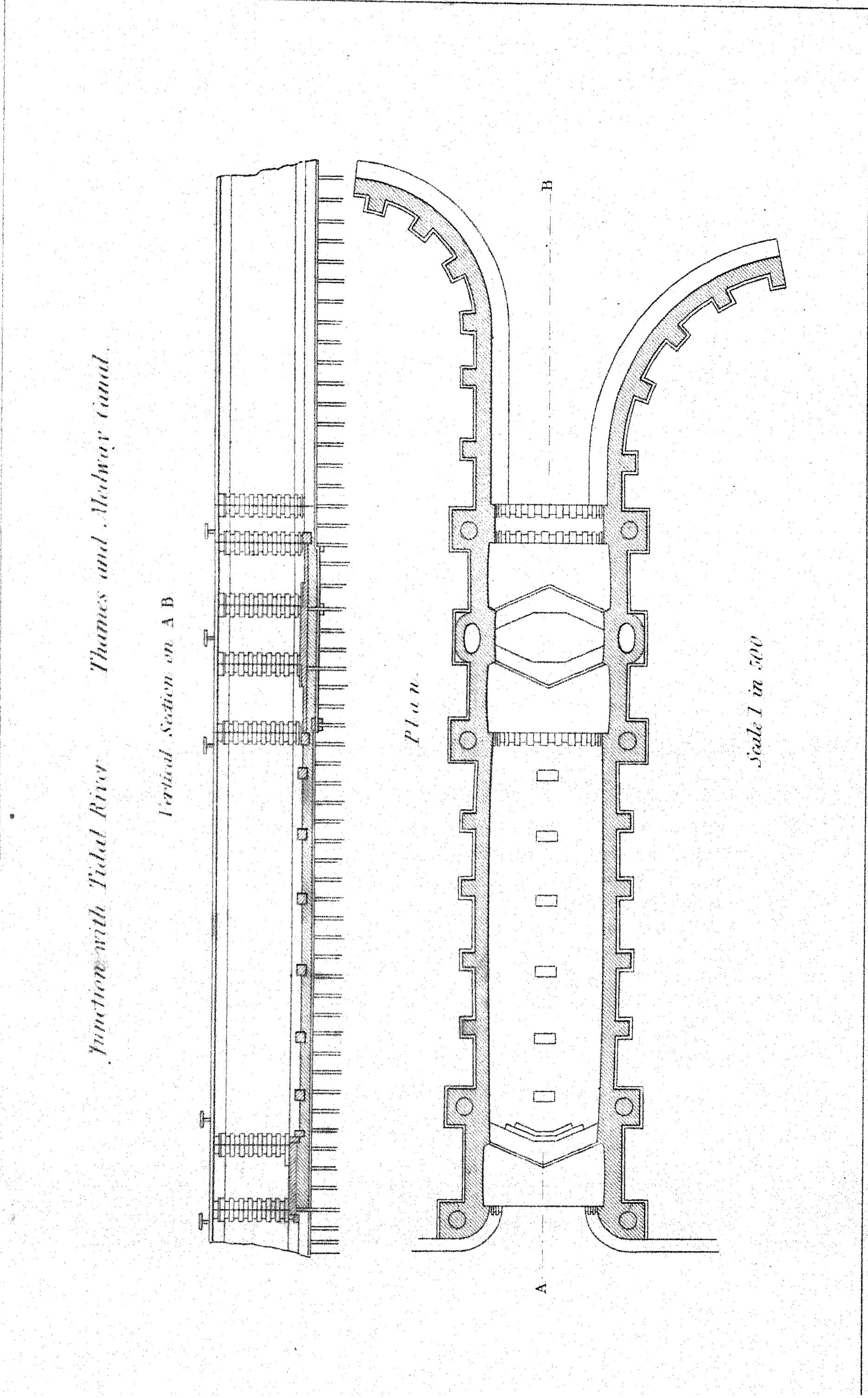
ROADS.*

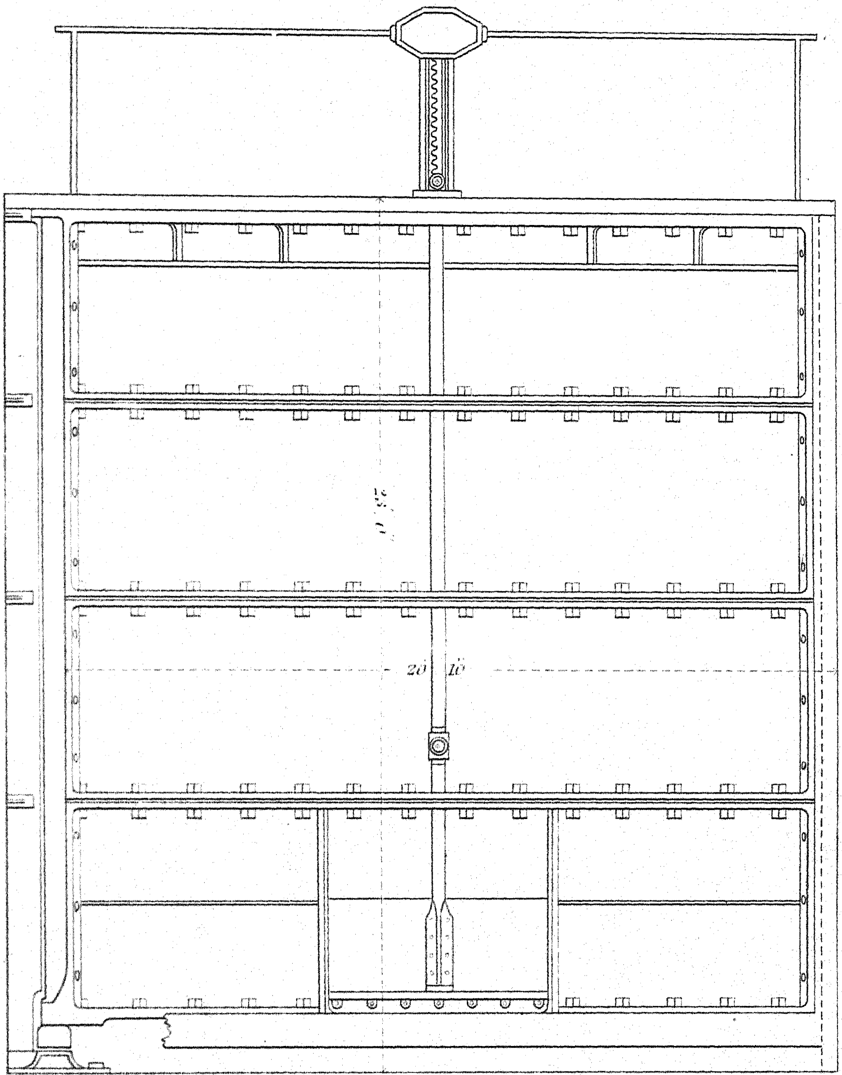
PART I.—TRACING AND CONSTRUCTION.

SECTION I.—TRACING OF ROADS.

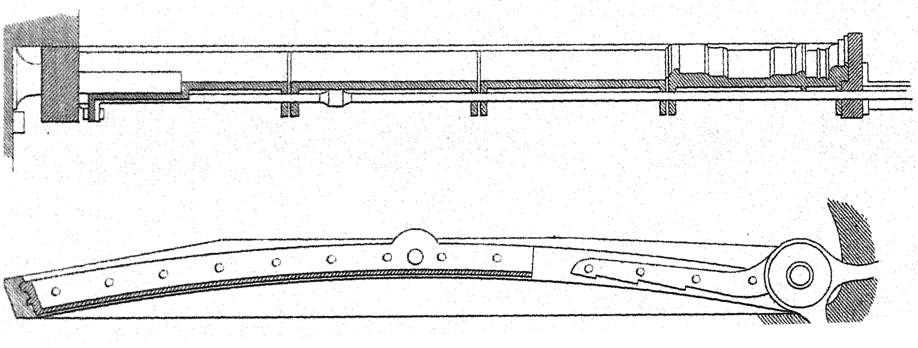
No surer indication can be afforded of the extent of a country's trade, or even of its advancement in civilization, than the existence of good and sufficient means of internal communication. For since it is one of the wise dispensations of Providence that many of those commodities which the present artificial state of society teaches us to regard as necessaries, are very unequally distributed, some being wanting in

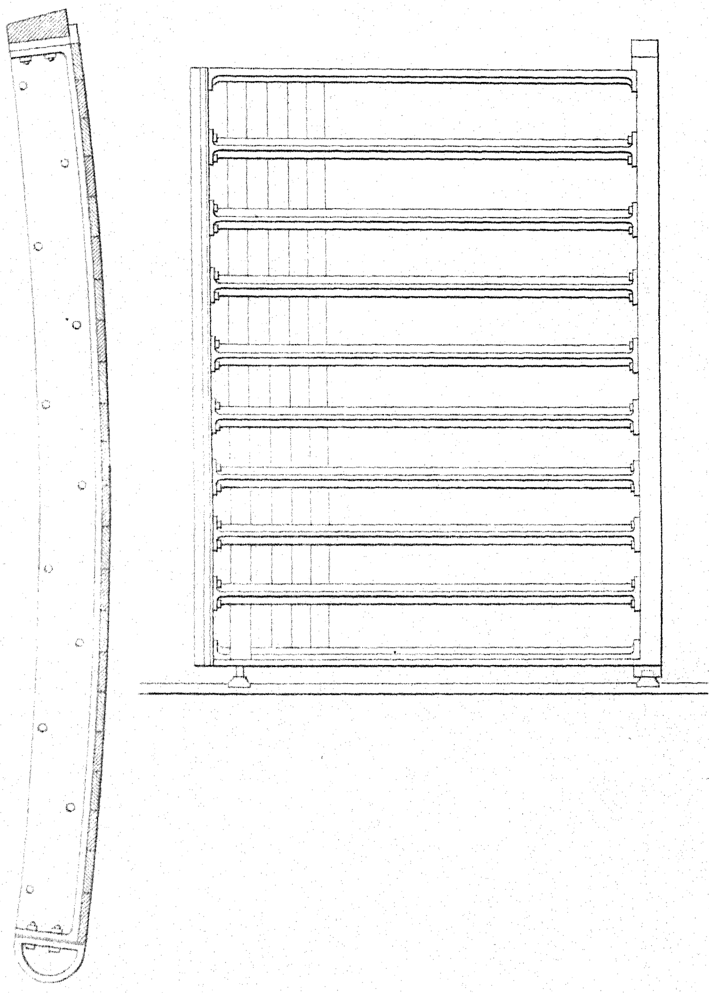
* By Henry Law, C. E.

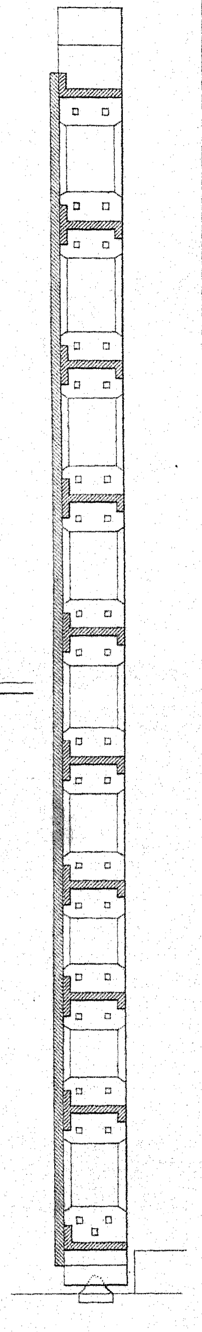

Junction with Tidal River Thames and Medway Canal.
Vertical Section on A B
Plan
Scale 1 in 500
A
B



Cast Iron Gates of the Canal of S.t Denis
Dep.t de la Seine, France.





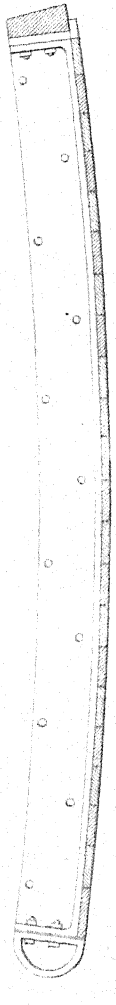


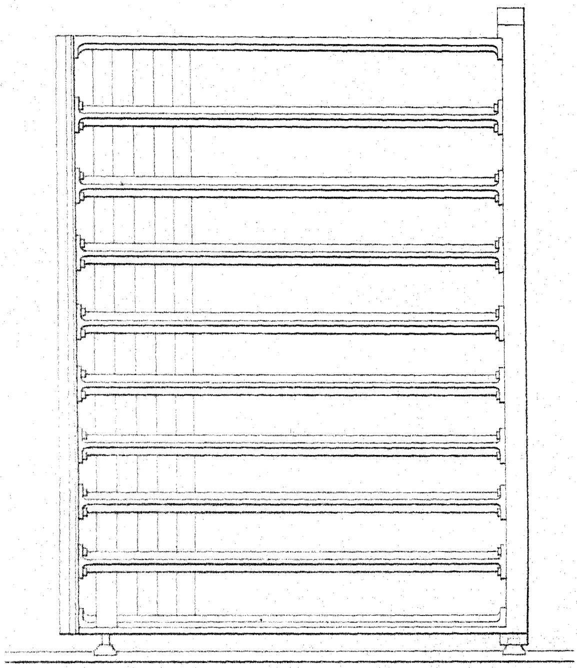
Lock Gates of the

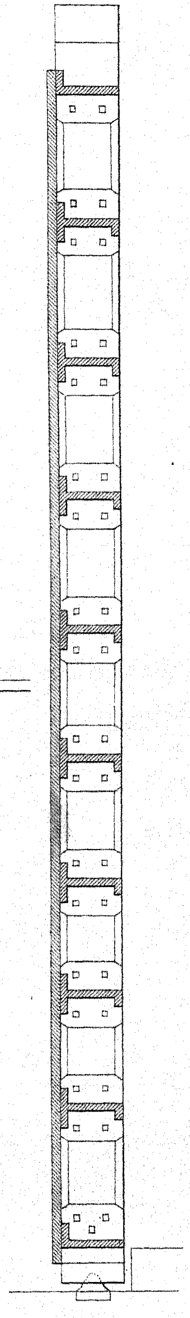
CALEDONIAN CANAL

of Cast Iron lined with Wood Planks

Scale of Elevation 1 in 100







Lock Gates of the

CALEDONIAN CANAL

of Cast Iron lined with Wood Planks

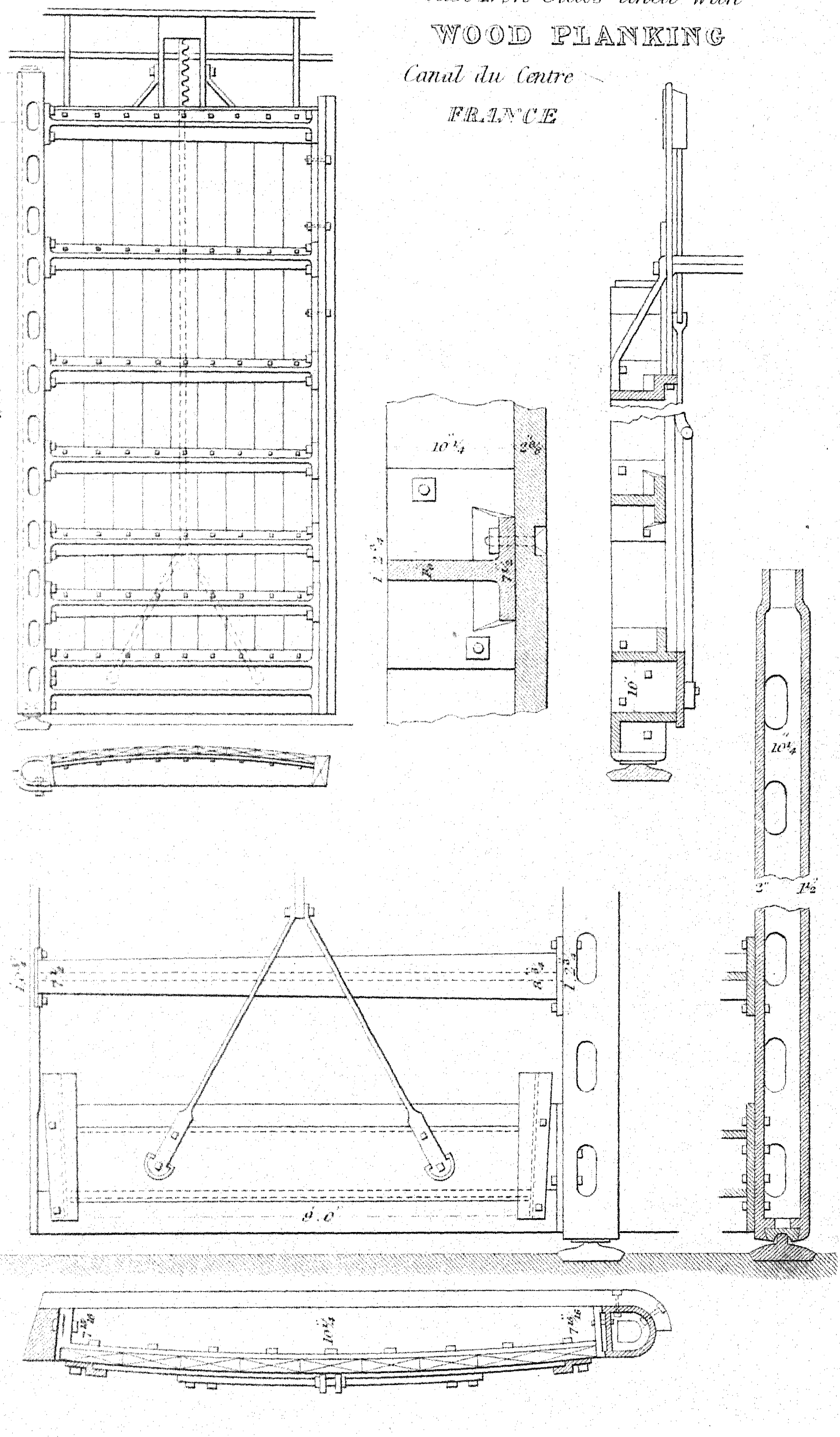
Scale of Elevation 1 in 100

Cast Iron Gates lined with

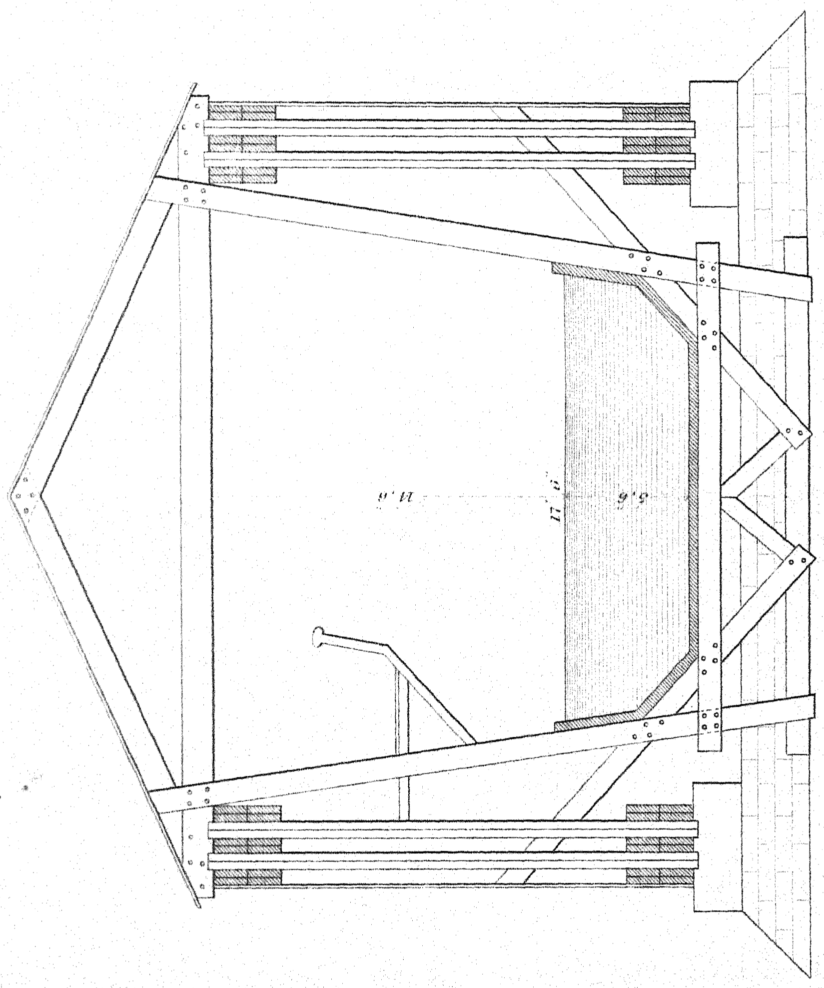
WOOD PLANKING

Canal du Centre

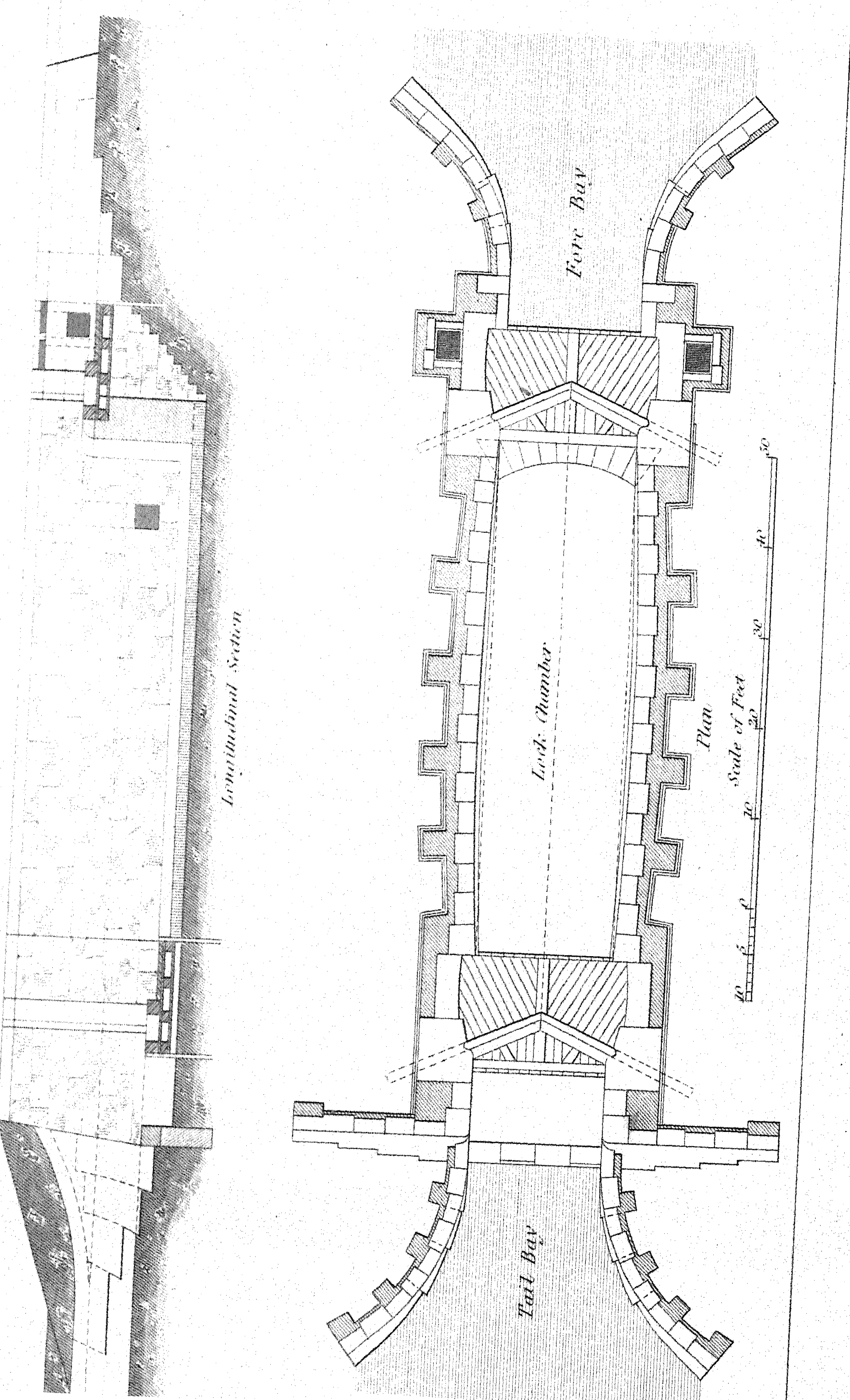
FRANCE



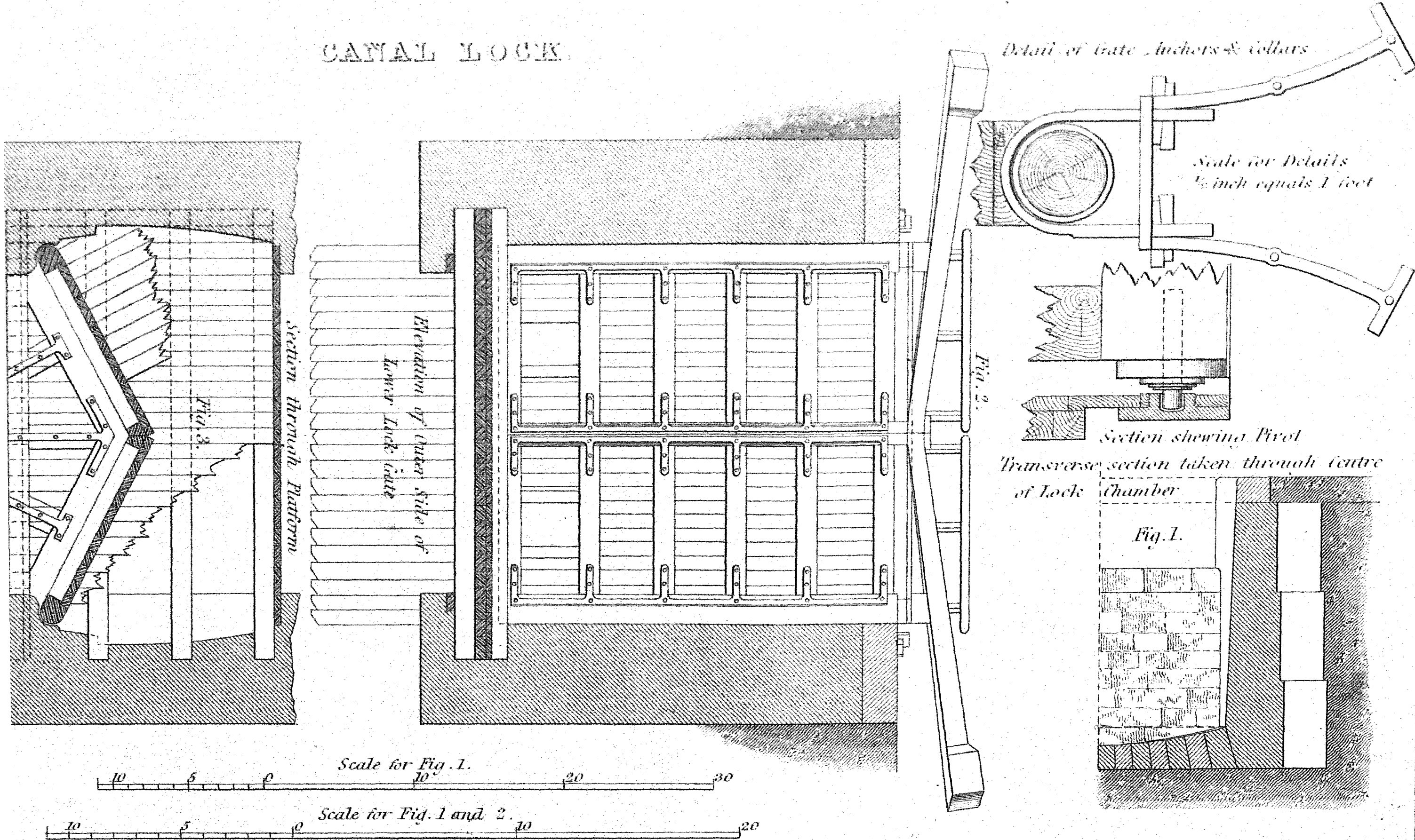
Wooden Aqueduct over the Potomac Georgetown Columbia U.S.



CANAL LOCK.

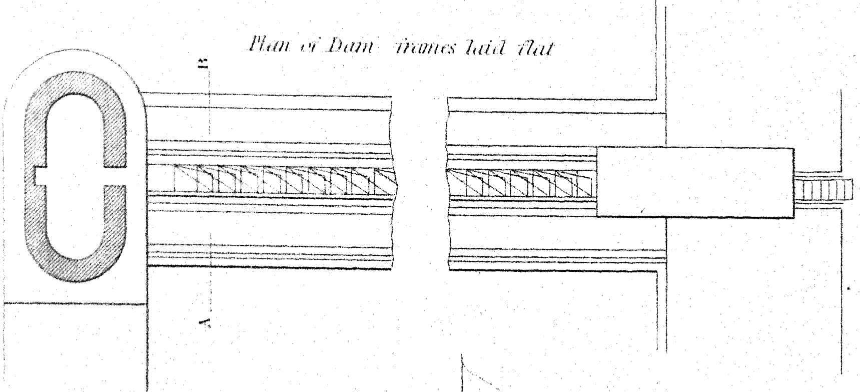

Longitudinal Section
Fore Bay
Lock Chamber
Plan
Scale of Feet
10 5 0 10 20 30 40 50
Tail Bay

CANAL LOCK.

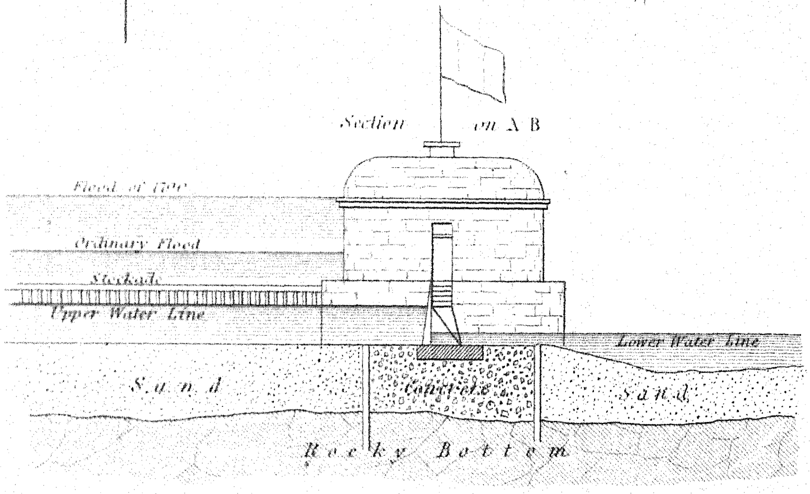

Detail of Gate Anchors & Collars
Scale for Details
½ inch equals 1 foot
Fig. 2.
Section shewing Pivot
Transverse section taken through Centre of Lock Chamber
Fig. 1.
Elevation of Outer Side of Lower Lock Gate
Section through Platform
Fig. 3.
Scale for Fig. 1.
10 5 0 10 20 30
Scale for Fig. 1 and 2.
10 5 0 10 20

Moveable Dam near Bezons, Department of the Seine No. 2.

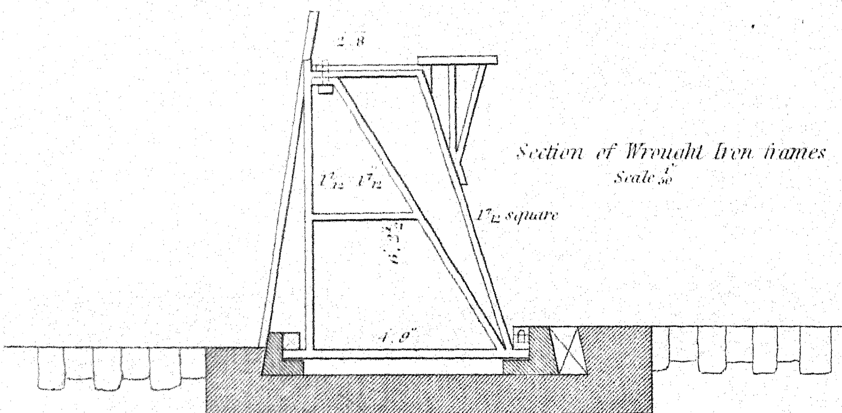
Plan of Dam frames laid flat



Section on A B



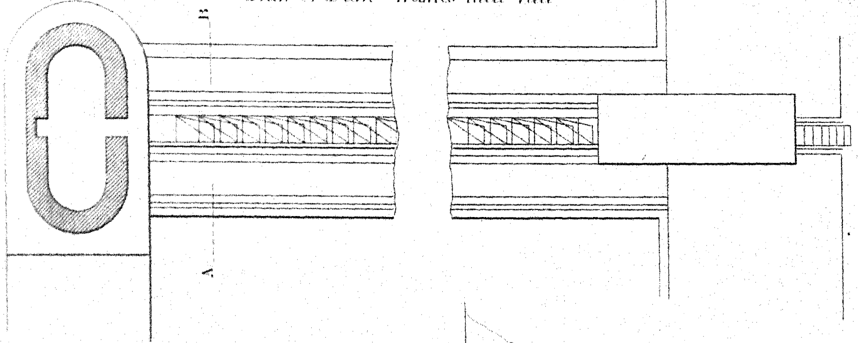
Section of Wrought Iron frames
Scale $\frac{1}{36}$



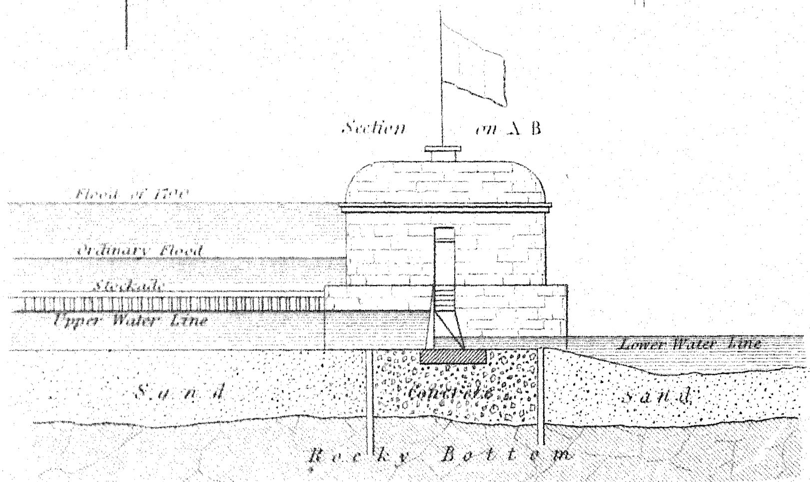
Concrete filling paved on top

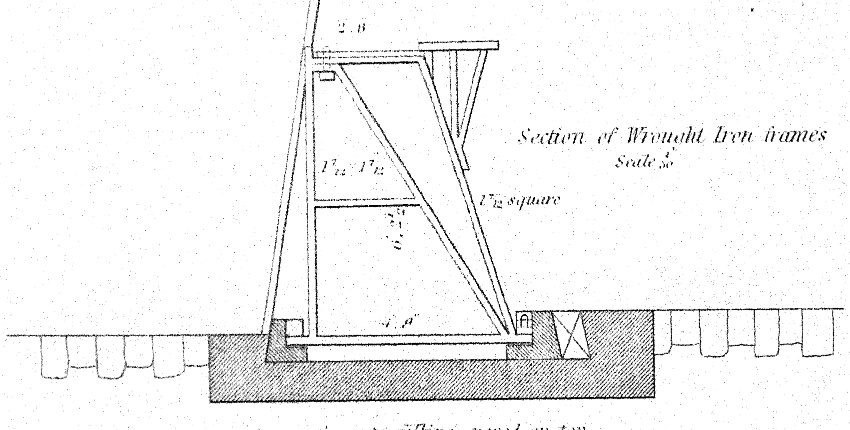
Moveable Dam near Bezons, Department of the Seine No. 2.

Plan of Dam frames laid flat



Section on A B



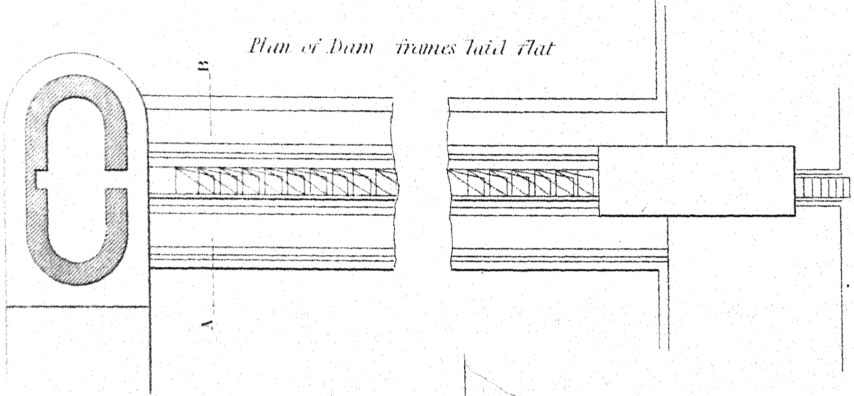


Section of Wrought Iron frames
Scale $\frac{3}{8}$

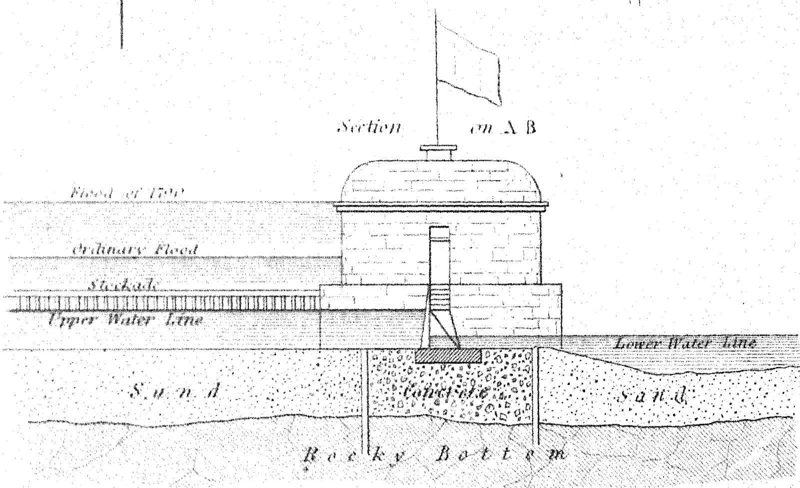
Concrete filling paved on top

Moveable Dam near Bezons, Department of the Seine No. 2.

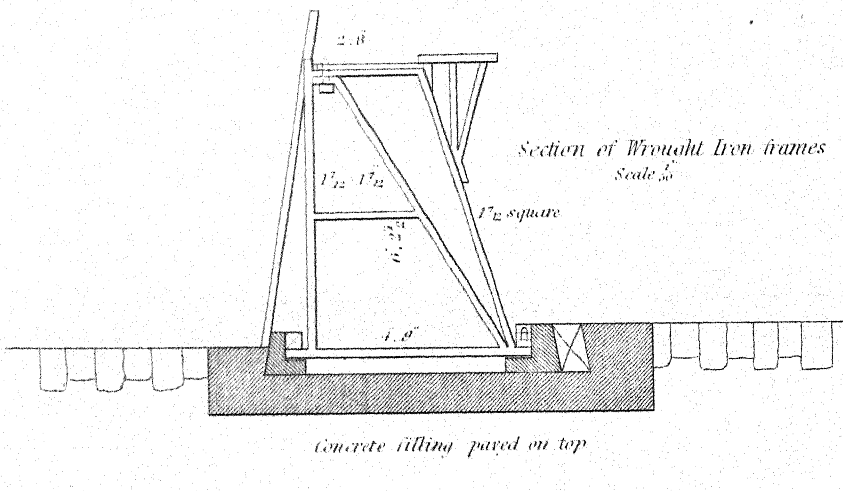
Plan of Dam frames laid flat



Section on A B



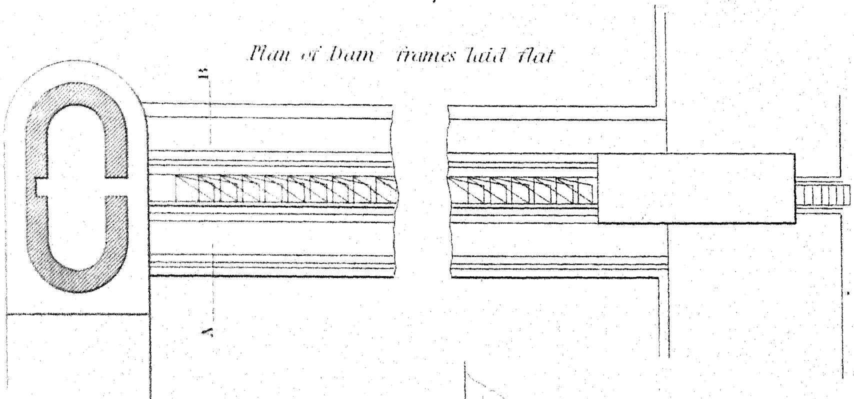
Section of Wrought Iron frames



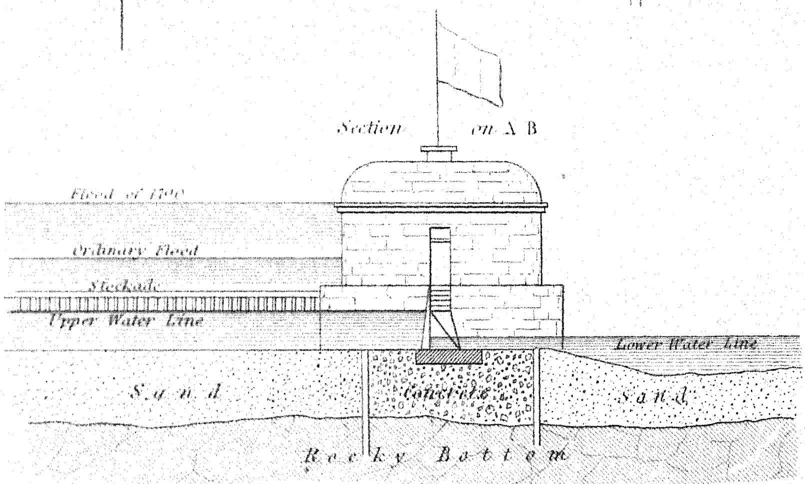
Concrete filling paved on top

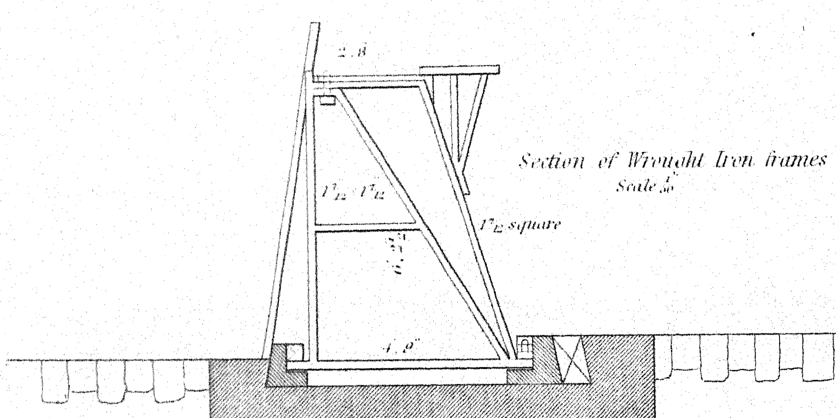
Moveable Dam near Bezons, Department of the Seine No. 2.

Plan of Dam frames laid flat



Section on A B



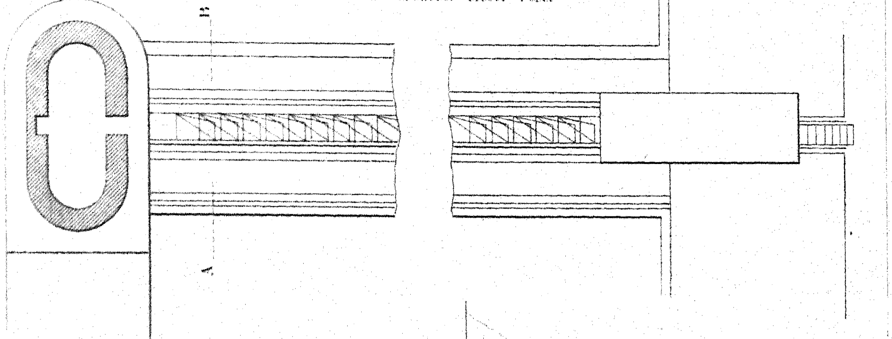


Section of Wrought Iron frames
Scale $\frac{1}{30}$

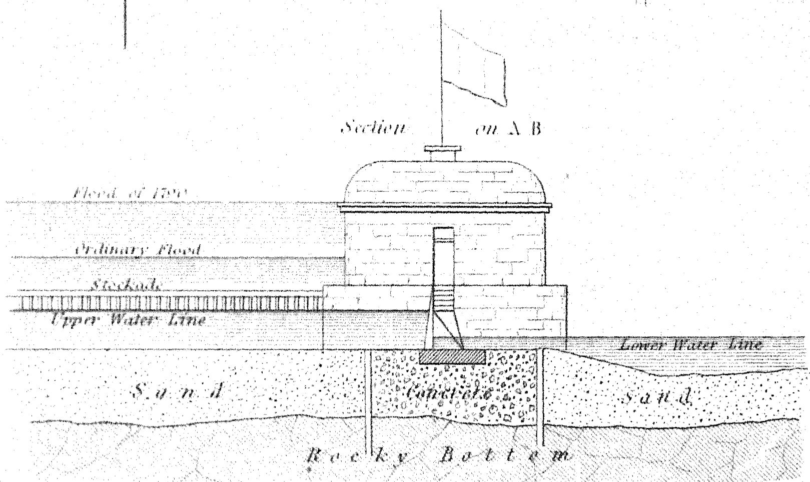
Concrete filling paved on top

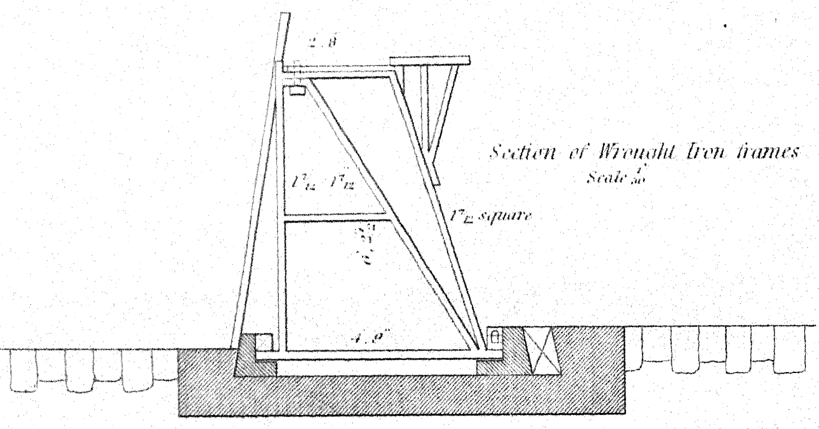
Moveable Dam near Bezons, Department of the Seine No. 2.

Plan of Dam frames laid flat



Section on A B



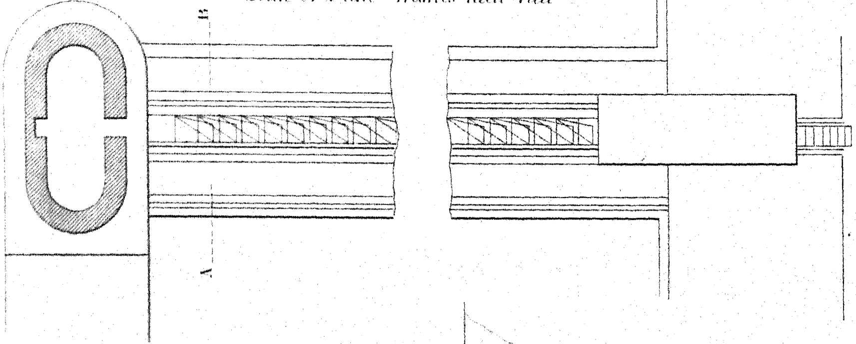


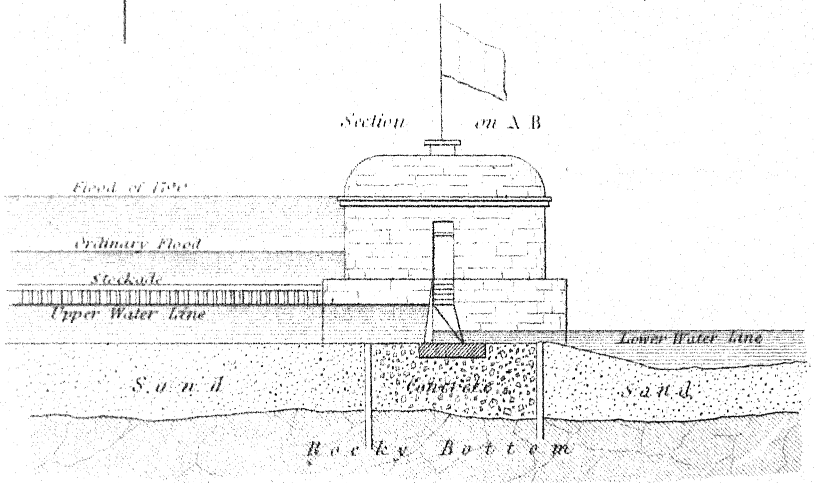
Section of Wrought Iron frames
Scale $\frac{1}{30}$

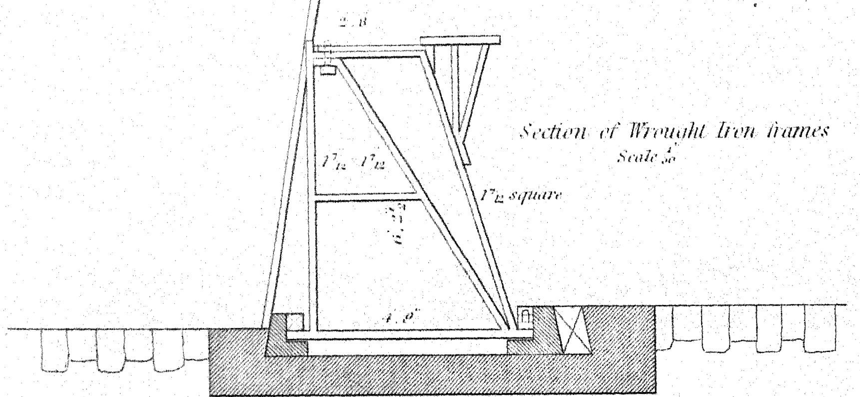
Concrete filling paved on top

Moveable Dam near Bezons, Department of the Seine No. 2.

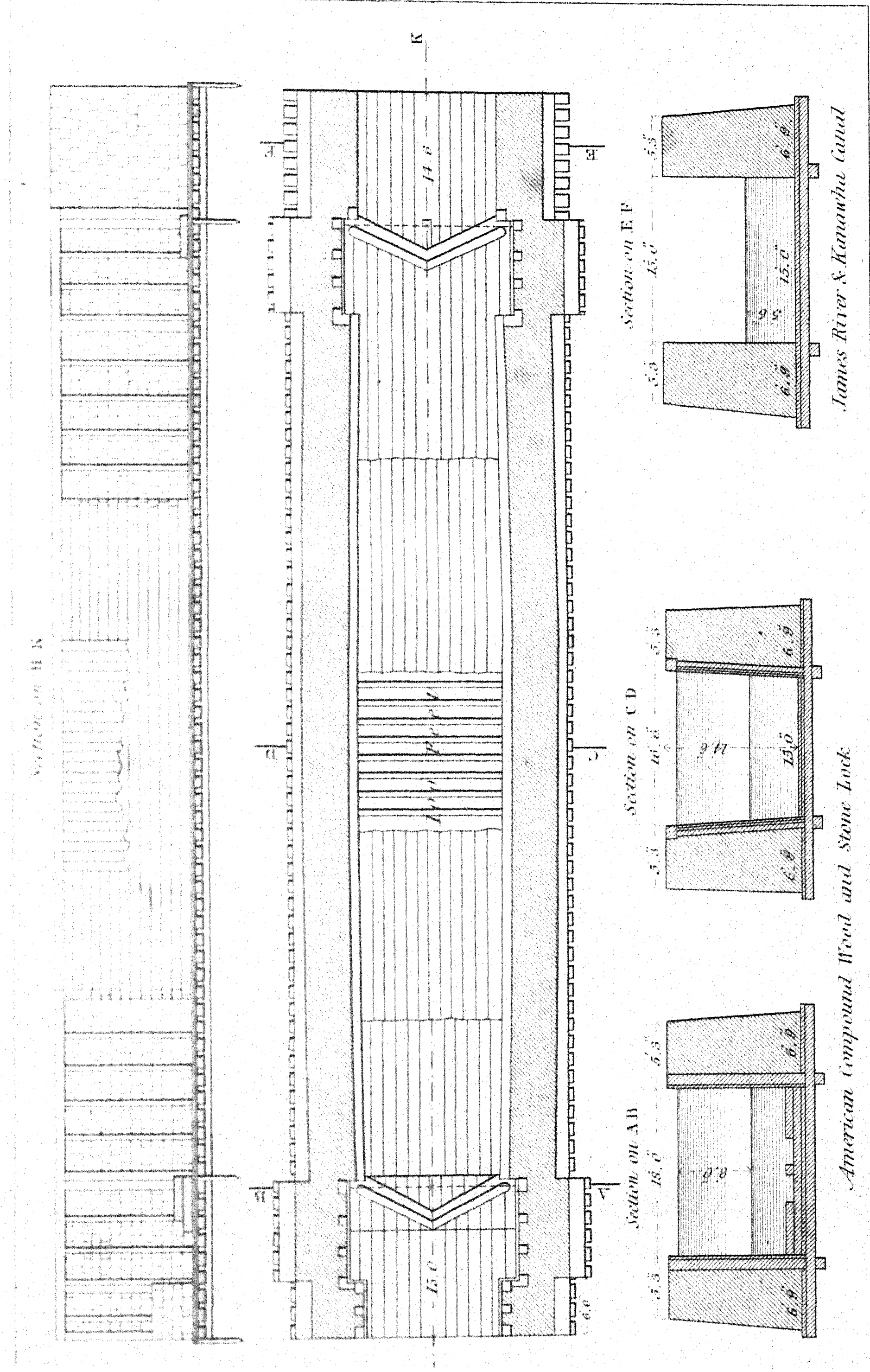
Plan of Dam frames laid flat

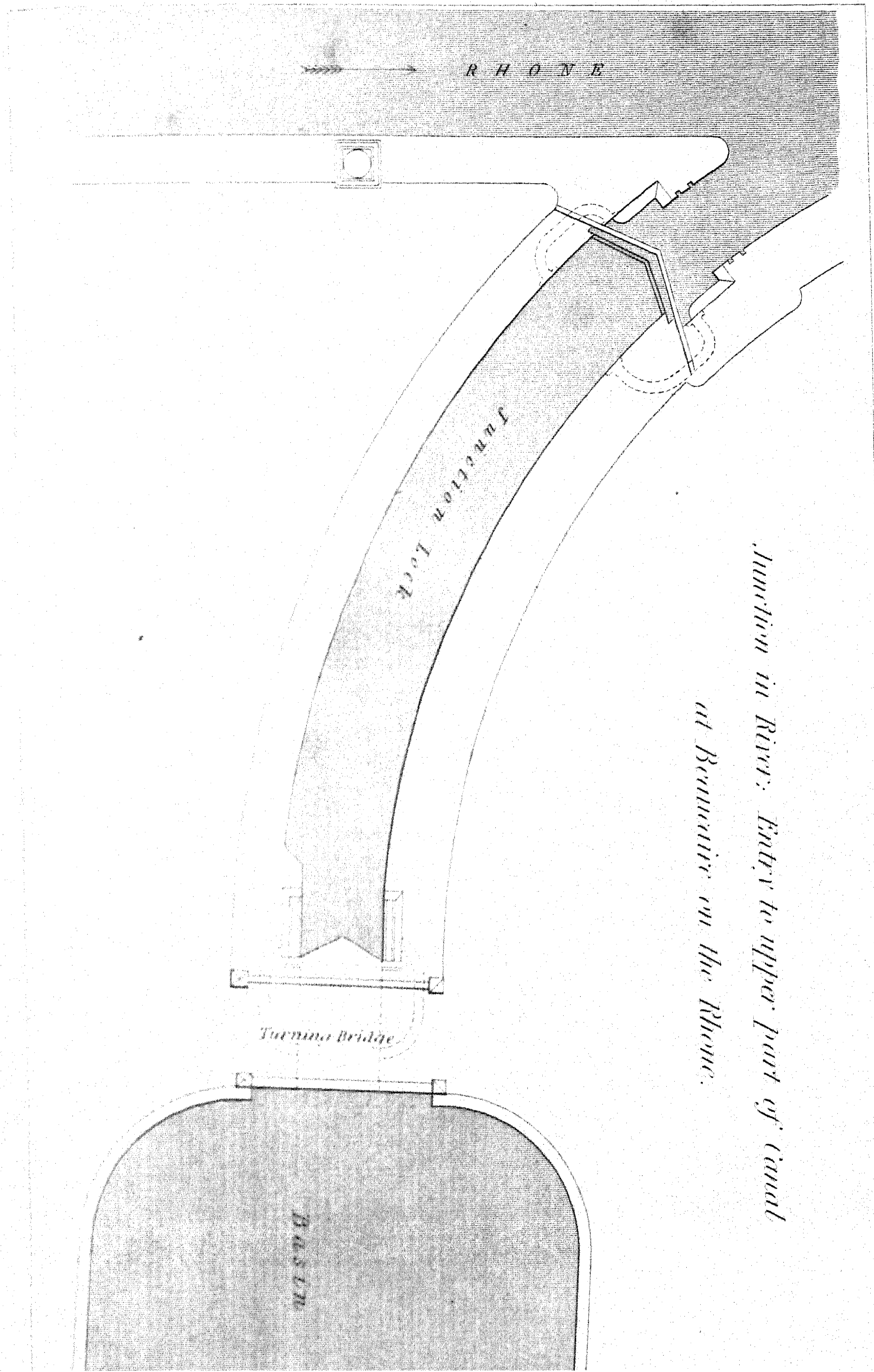






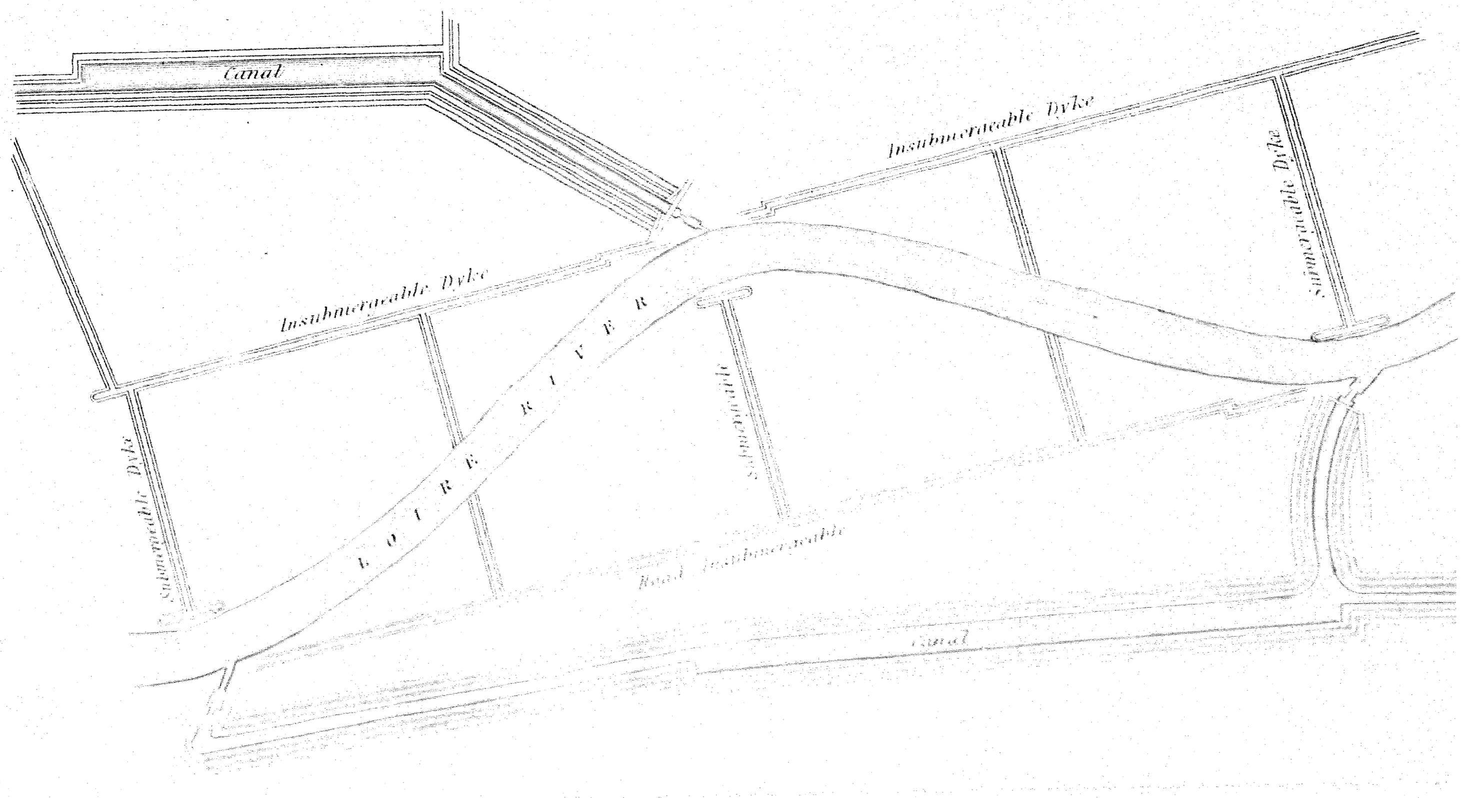
Concrete filling paved on top

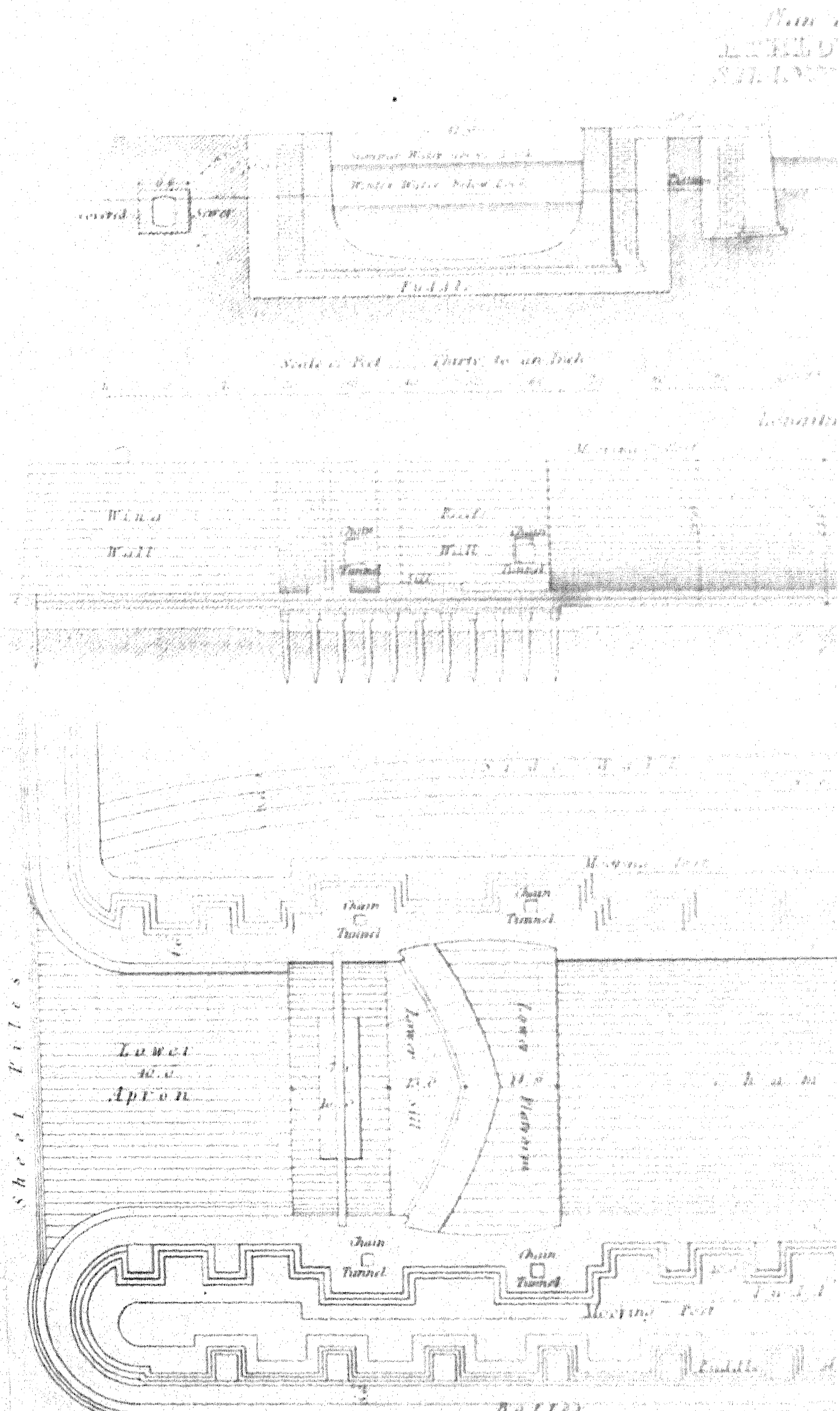

Section on A B
Section on C D
Section on E F
American Compound Wood and Stone Lock
James River & Kanawha Canal
14.6
15.0
15.0
6.9
5.3



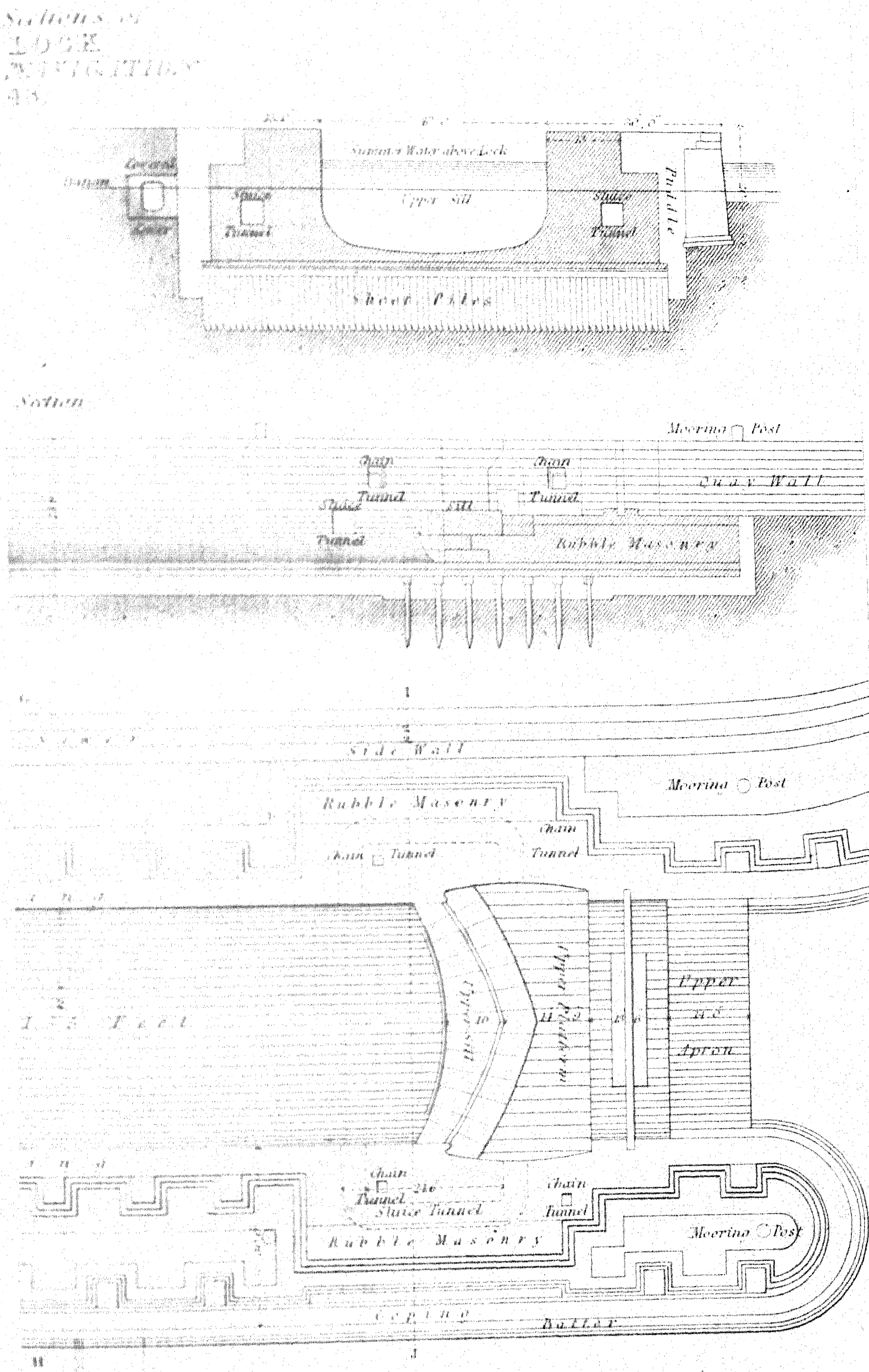
Junction in River; Entry to upper part of Canal at Beaucaire on the Rhone.

Example of a Passage from one Bank of a River to the other
Lateral Canal of the Loire. Châtillon sur Loire





Puddle
Scale of Feet ... Thirty to an Inch
Wing Wall
Back Wall
Chain Tunnel
Meeting Post
Sheet Piles
Lower W.G. Apron
Lower W.G. Sill
Lower W.G. Platform


Summer Water above Lock
Upper Sill
Sluice
Tunnel
Puddle
Sheet Piles
Section
Mooring Post
Chain
Tunnel
Quay Wall
Sill
Rubble Masonry
Side Wall
Mooring Post
Rubble Masonry
Chain
Tunnel
Upper Sill
Upper Apron
Chain
Tunnel
Sluice Tunnel
Rubble Masonry
Mooring Post
Coping
Batter

certain localities where again others are only found, it becomes necessary, in order that all may be equally well served, that an interchange of these commodities should take place, so that the whole country may participate equally in the enjoyment and use of those things which would otherwise be confined to only certain districts. Thus, we may have in one part of a country huge forests, stocked with various kinds of timber; in another, extensive tracts of fertile land, capable, if properly cultivated, of yielding supplies of corn and other produce, sufficient for the support of a densely-populated country; in a third, mineral treasures, coal and iron, or the more precious metals; in another, stone, well adapted for the construction of houses, and for other building purposes: and yet, with all these latent treasures dispersed throughout the country, of what avail would they be, unless the means were possessed of conveying them to every part of the land, and thus distributing to all what would otherwise be enjoyed but by a few?

It is not, however, only for the purposes of its own internal trade that good means of communication are required; they become even more necessary, to insure an extensive commerce with foreign countries, to enable the peculiar produce of the several districts to be brought together to those parts of the coast which have been either naturally or artificially formed into ports, and then again to distribute to every part of the country the goods brought in exchange from foreign lands, comprising frequently the necessaries as well as the luxuries of human life.

And further, good means of internal communication are essential for the proper defence of a country (whether island or continental) against either the attacks of foreign aggressors or civil tumults, rendering a much smaller standing army necessary for this purpose than would otherwise be required.

Such being the case, it will not be a matter of surprise that, from the earliest periods, and in all nations having any pretensions to civilization, the establishment and improvement of the means of internal communication has always been regarded as a consideration of primary importance; and one which has engaged the highest talents of the Military or Civil Engineer, the result of whose exertions, devoted to the accomplishment of this object, has been the perfection of common roads, railways, and canals.

It is not necessary to enter into the comparative merits or advantages of these several means of communication, in order to establish the importance and necessity of common roads. For although, under certain circumstances, it might be questionable which of the three would be the best adapted for serving the tract of country through which it was to pass, there are an innumerable number of cases in which only the common road could be advantageously employed. Railways and navigable rivers or canals may be regarded as the arteries of traffic; while common roads are simply the veins or smaller ramifications through which the means of conveyance are carried into every nook and corner of the land. It would be quite impracticable so to intersect any country with canals or railways as to obviate the necessity of common roads, or to make the former universally supersede the latter.

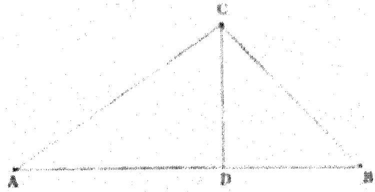
The formation of a perfect general system of railway communication necessitates the construction of several new common roads, in order that towns situated at some distance from the nearest line of railway may fully participate in the benefits to be derived from it.

Before entering into practical details on the construction of such roads, it will be desirable to explain the manner in which a person should proceed in exploring a tract of country for the purpose of determining the best course for a road, and the principles which should guide him in his final selection of the same.

Let us suppose that it is desired to form a road between two distant towns, A and B,

fig. 1, and let us, for the present, neglect altogether the consideration of the physical features of the intervening country; assuming that it is equally favourable, whatever

Fig. 1.



line we select. At first sight, it would appear that, under such circumstances, a perfectly straight line drawn from one town to the other would be the best that could be chosen. On a more careful examination, however, of the locality, we may find that there is a third town, C, situated somewhat on one side of the straight line which we have drawn from A to B; and, although our primary object is to connect only the two latter, that it would, nevertheless, be of considerable service if the whole of the three towns were put into mutual connection with each other. Now this may be effected in three different ways; any one of which might, under certain circumstances, be the best. In the first place, we might, as originally suggested, form a straight road from A to B, and in a similar manner, two other straight roads from A to C, and from B to C, and this would be the most perfect way of effecting the object in view; the distance between any two of the towns being reduced to the least possible. It would, however, be attended with considerable expense, and it would be requisite to construct a much greater length of road than according to the second plan, which would be to form, as before, a straight road from A to B, and from C to construct a road which should join the former at a point D, so as to be perpendicular to it; the traffic between A or B and C would proceed to the point D, and then turn off to C: with this arrangement, while the length of the roads would be very materially decreased, only a slight increase would be occasioned in the distance between C and the other two towns. The third method would be to form only the two roads A C and C B, in which case the distance between A and B would be somewhat increased, while that between A and C, or B and C, would be diminished; the total length of road to be constructed would also be lessened.

As a general rule, it may be taken, that the last of these methods is the best, and most convenient for the public; that is to say, that if the physical character of the country does not determine the course of the road, it will generally be found best not to adopt a perfectly straight line, but to vary the line so as to pass through all the principal towns near its general course; for the reason that the public may be conveyed from town to town with greater facility and less expense than if the straight line were adopted, and the towns were merely made to communicate with it by means of branch roads: since, with the first arrangement, any vehicles established to convey passengers or goods between the two terminal towns would pass through all those which were intermediate; while, if the straight line and branch-road system were adopted, it would be requisite also to have a system of branch coaches to meet the coaches on the main line.

In laying out a road in an old country which has been long inhabited, and in which the position of the various towns, &c., requiring road accommodation is therefore already determined, we are left less at liberty in the choice and selection of the line of road, and must be guided in that choice by different considerations to those which would determine the line of a road made through a new country, where our only object was to establish the easiest and best road between two distant

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